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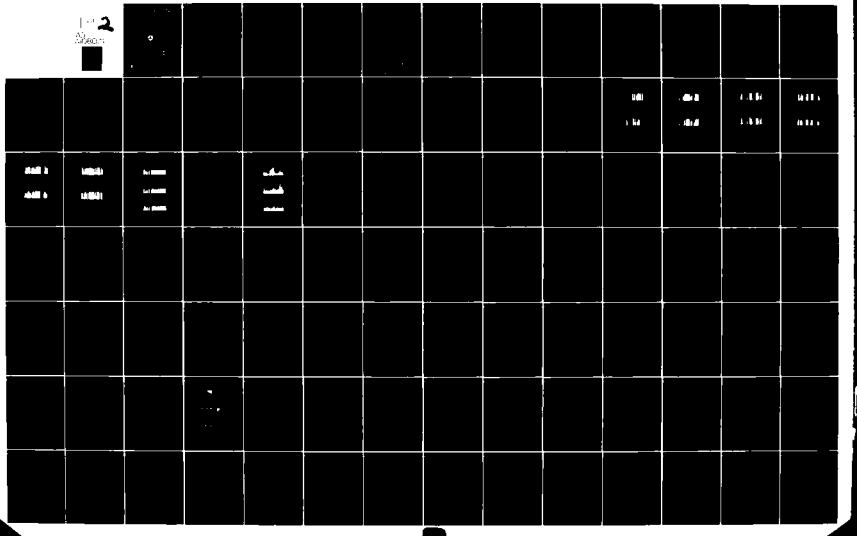

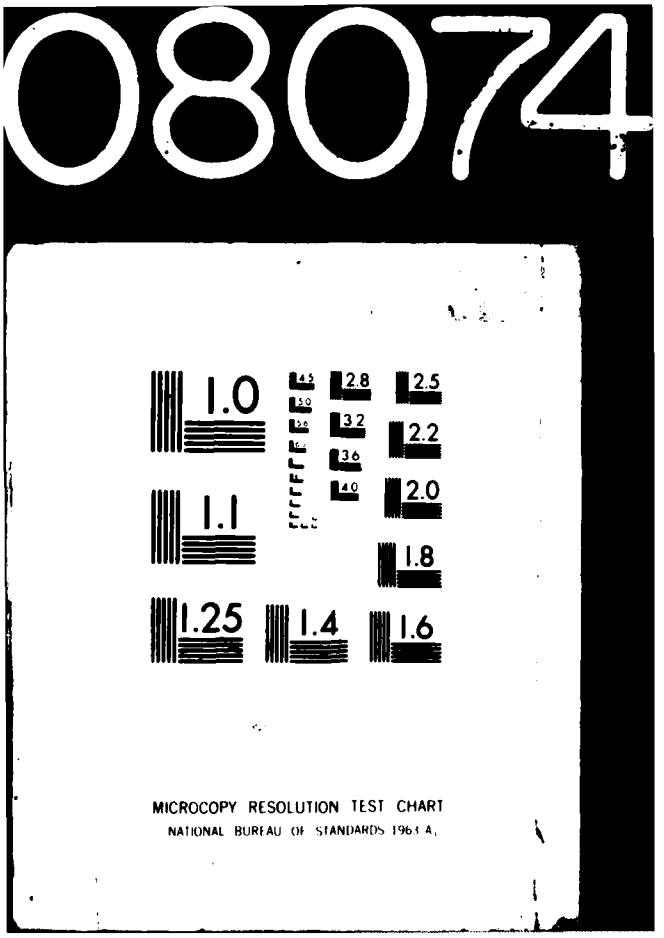
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Report No. CG-D-52-81

LEVEL II

12

QUANTIFICATION OF ST. MARYS RIVER LORAN-C TIME DIFFERENCE GRID INSTABILITY

THE ANALYTIC SCIENCES CORPORATION
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READING, MASSACHUSETTS 01867

AUGUST 1980

FINAL REPORT

VOLUME 1

TEMPORAL INSTABILITY

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20590

NOTICE

METRIC CONVERSION FACTORS

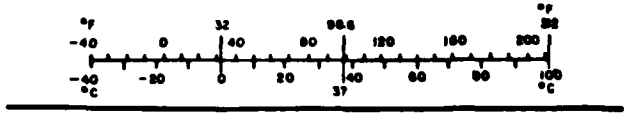
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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16. Abstract

Time Difference (TD) data collected in the St. Marys River Loran-C chain coverage area between May 1979 and May 1980 are analyzed to quantify previously-reported temporal TD grid instability. The data included TD samples, nominally recorded every 15 min. at three fixed site monitors and the System Area Monitor (SAM), Local Phase Adjustment (LPA) data, and meteorological data from the National Weather Service Station at Sault Sainte Marie, Michigan. Assorted non-parametric data analyses, including spectral and correlation analyses, are conducted to separate diurnal and seasonal components of grid instability and identify relationships among the various TDs. The relative magnitude of the seasonal TD variations and the correlation of pairs of TDs are not consistent with expected weather-related variations in signal propagation time, thereby suggesting that the grid instability may be partially transmitter and/or receiver-related. The Loran-C data are also employed to evaluate the U.S. Coast Guard low-density (five 15-min. samples, twice daily) data analysis approach. The low-density approach is found to be adequate for monitoring seasonal TD variations, but inadequate for monitoring diurnal variations. An increase in the sampling rate is recommended for low-density Loran-C data collection in harbors.

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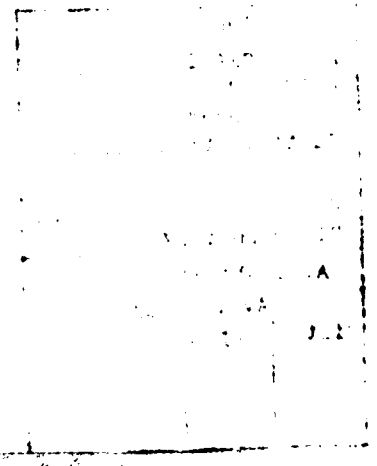

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1. INTRODUCTION

1.1 BACKGROUND

The U.S. Coast Guard conducted a comprehensive data collection effort from May 1979 to May 1980 to quantify an apparent temporal instability in the St. Marys River Loran-C Time Difference (TD) grid. Detailed analyses of the resulting Loran-C data base are documented in this report.

TASC's involvement with the St. Marys River Loran-C mini-chain began with the calibration of a spatial TD grid prediction model based on data collected during September and October 1977 (Refs. 1 and 2). A limited amount of data collected monthly between November 1977 and March 1978 exhibited temporal TD variations as large as 0.4 μsec peak-to-peak at some data collection sites. Because the utility of the TD grid prediction model and the mini-chain depends on the assumption of a stable grid, it was important that the validity of the observed temporal variations be confirmed. In particular, collection of additional data under more carefully controlled conditions (e.g., well-sheltered receivers and ideal grounding) was judged to be necessary. The need for confirmation was further highlighted by a theoretical sensitivity analysis, which revealed that the observed TD variations could not be explained by expected seasonal variations in signal propagation conditions (Ref. 3). In order to resolve the discrepancy between the theory and observations, it was recommended that the U.S. Coast Guard initiate the yearlong data collection effort outlined in Ref. 4. Loran-C Data-Base Management Software was subsequently designed and implemented at TASC, to support the editing and analysis of the collected data (Ref. 5).

The data consist of TD samples and associated signal-quality indicators, recorded nominally every 15 min at three fixed sites: DeTour Village, Dunbar Experimental Forest, and Pt. Iroquois* (see Fig. 1.1-1). Two Internav LC-204 Loran-C receivers are located at both the DeTour and Iroquois sites, and one Internav LC-204 and one Magnavox AN/BRN-5 receiver are located at the Dunbar site.† The BRN-5 receiver is interfaced with a cesium frequency standard to also provide measurements of Time-of-Arrival (TOA). The following additional data are collected to support the analyses: System Area Monitor (SAM) TDs from the Austron-5000 receiver used for chain control, Local Phase Adjustments (LPAs) from the Calculator Assisted Loran Controller (CALOC) system, and meteorological data from the National Weather Service Station at Sault Sainte Marie, Michigan.

In addition to the 15-min TD data, which are termed high-density data, the U.S. Coast Guard collects low-density data for in-house analyses. The low-density data are recorded with a microprocessor-based system which is independent of the Texas Instruments Silent 700 cassette tape recorder used to obtain the high-density data. The low-density data consist of five 15-min samples recorded twice daily, which are then averaged and transmitted over a telephone data link in a weekly message. A similar low-density data-recording system is under development by the U.S. Coast Guard for use in harbor and harbor entrance Loran-C navigation experiments.

*Referred to as DeTour, Dunbar, and Iroquois in this report.

†Referred to as LC-204 and BRN-5 in this report.

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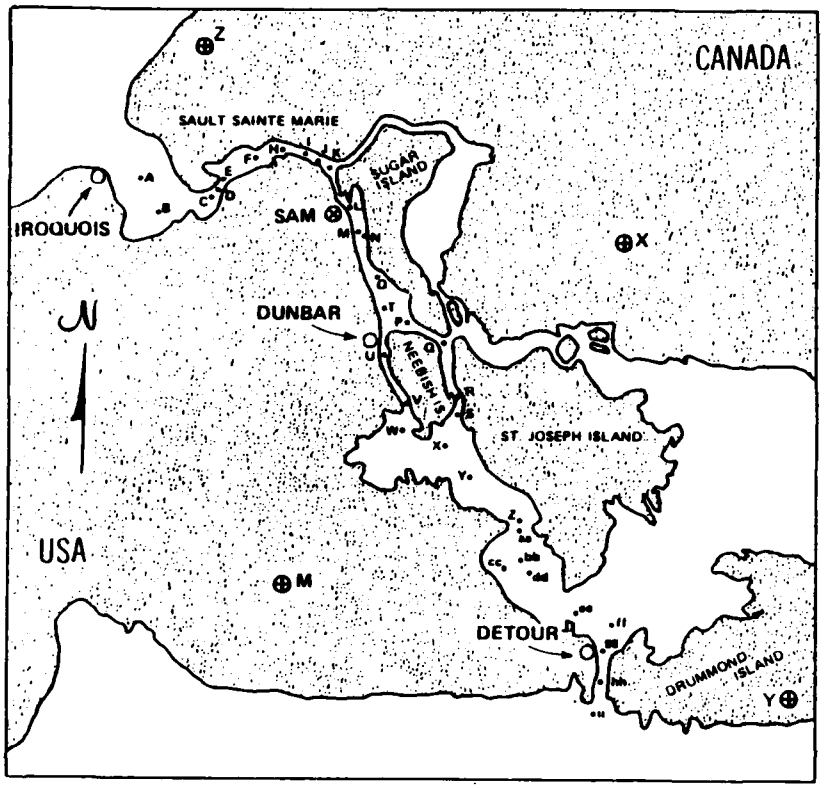


Figure 1.1-1 Locations of River Waypoints, Data Collection Sites, and Transmitters in Reconfigured St. Marys River Loran-C Mini-Chain

1.2 OBJECTIVES

The objectives of the study documented herein, as indicated in Fig. 1.2-1, are to:

- Conduct high-density data analyses to quantify TD grid instability in the St. Marys River Loran-C mini-chain

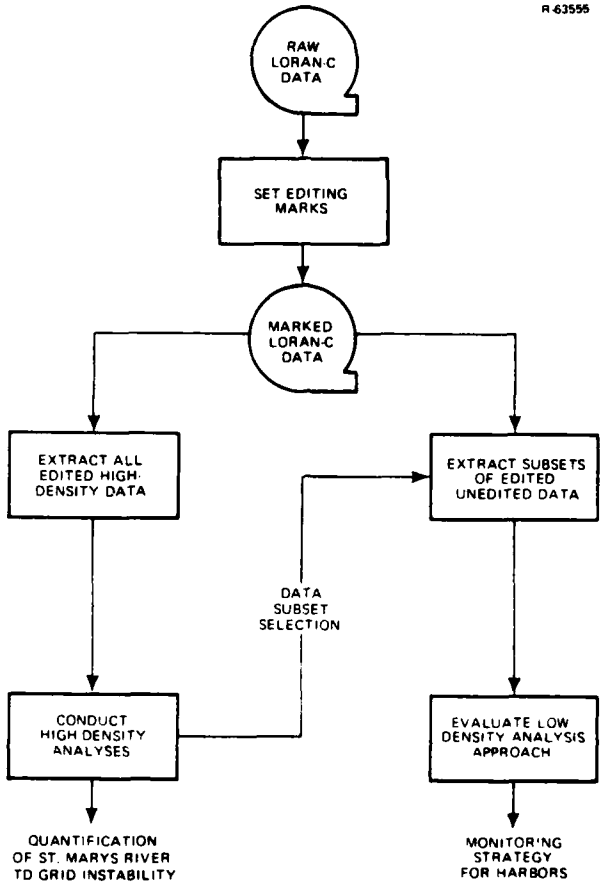


Figure 1.2-1 Objectives and Technical Approach for St. Marys River Temporal Loran-C Data Analyses

- Evaluate the low-density data analysis approach to establish an efficient Loran-C monitoring strategy for harbors.

To meet these objectives, the raw Loran-C data are first organized and edited, using the TASC Loran-C Data-Base Management Software. Editing marks are set by the software to indicate the quality of each TD sample, thus making it straight-

forward to extract "good" and/or "bad" data without affecting the master data base. Specifically, a criterion for editing is selected for the high-density analyses, and all corresponding data are extracted and analyzed (see Fig. 1.2-1). Availability of the high-density analysis results then permits the low-density evaluation to be limited to a subset of all possible site/receiver/TD combinations. Both edited and unedited TD data are extracted for the selected combinations to determine the effect of outliers on the low-density approach.

It should be kept in mind that the primary objective of the high-density data analyses is to quantify TD grid instability. Although the determination and modeling of cause/effect relationships is beyond the scope of the current effort, the analyses are selected and presented in a manner which facilitates possible future studies by the U.S. Coast Guard. A comparison is made between the data analysis results herein and the theoretical sensitivity analysis results from Ref. 3, to provide a basis for future research.

1.3 REPORT OVERVIEW

A description of the Loran-C data base and editing procedure is provided in Chapter 2. The high-density data analysis results are given in Chapter 3 and the low-density data analysis approach is evaluated in Chapter 4. The study conclusions are contained in Chapter 5, together with a recommended sampling/editing/analysis strategy for harbor Loran-C monitor data.

The TASC Loran-C data base is being delivered to the U.S. Coast Guard on three magnetic tapes which supplement this report. The tape layouts are described in Section 2.6 and the record formats are given in the appendices.

2. DESCRIPTION OF DATA BASE AND EDITING PROCEDURE

2.1 INTRODUCTION

Data from the St. Marys River temporal TD instability experiment are provided to TASC on 11 half-inch magnetic tapes with the record format listed in Appendix A. The tapes contain a total of 137 site files, 286 SAM files, and 11 weather files, which are sorted and ordered by the Loran-C Data-Base Management Software. The record formats are changed to those presented in Appendices B and C, which include six editing mark characters for every TD and TOA sample.

2.2 EDITING PROCEDURE

The editing marks indicate the quality of the data, each mark corresponding to a different editing operation as indicated in Table 2.2-1. The manner in which the editing marks are determined is detailed in Ref. 5 and summarized below.

2.2.1 Editing Mark 1: Loran-C Transmitter

Editing Mark 1 indicates which Loran-C transmitter is associated with the TOA, or which secondary transmitter is associated with the TD. In the cases of the LC-204 and BRN-5 receivers, the transmitter is determined by examining the first two digits of the TD. If the digits do not match one of the three possibilities -- "11" for TDX, "22" for TDY, or "33" for TDZ -- Editing Marks 1 to 6 are set to "?".

TABLE 2.2-1
INTERPRETATION OF EDITING MARK VALUES

EDITING MARK	OPERATION	VALUES*	INTERPRETATION
1	Loran-C Transmitter	M	TOAM
		X	TOAX or TDX
		Y	TOAY or TDY
		Z	TOAZ or TDZ
2	Signal Quality Check	0	Good Data Quality
		1	Control Unit Switch on B
		2	Insufficient Signal
		3	Both Characteristics 1 and 2 Apply
3	Tolerance Check	0	Data Differs from Seasonal Mean by $\leq$ 0.5 μsec
		1	0.5 μsec < Difference $\leq$ 1.0 μsec
		2	Difference > 1.0 μsec
4	Manual Editing	0	No Manual Editing
		6	Duplicate Data
5	Differential Correction Computation		Differential Correction Computed
		0	No Interpolation Required
		A	Interpolation Interval $\leq$ 6 hr
		B	6 hr < Interval $\leq$ 24 hr
		C	Interval > 24 hr
			Differential Correction Not Computed
		1	Uncertain LPA Times
		2	Bad SAM TD Data Based on Editing Marks 1 to 4 and 6
		3	No LPA and/or SAM TD Data Available
6	Outlier Editing	0	Data Is Not an Outlier
		1,2,3,4	Data Differs from Daily Trend Line by >0.05, 0.10, 0.15, 0.20 μsec (Second Iteration)
		5,6	Data Differs from Trend Line by >0.15, 0.20 μsec (First Iteration)
		S	Less Than 20 Samples per Day Available to Compute Trend Line
		U	Bad Data Based on Editing Marks 1 to 4

Editing marks [illegible] "*" if [illegible] and to "?" if not computable.

2.2.2 Editing Mark 2: Signal-Quality Check

Editing Mark 2 summarizes various Loran-C signal-quality indicators which appear in each data record. The indicators which are checked are SWITCH and SUFFSIG for the LC-204, SUFSIG for the BRN-5, and MODE for the Austron-5000 receiver (see Appendix A). Editing Mark 2 is the only editing mark which is not based on the TD/TOA data itself.

2.2.3 Editing Mark 3: Tolerance Check

Editing Mark 3 indicates whether or not the TD lies between expected lower and upper bounds, which are selected based on U.S. Coast Guard low-density data available at the beginning of the study. Specifically, the TD is compared to the mean of the low-density data for the period May 1979 to February 1980 (Ref. 5).* Three tolerance bands (see Table 2.2-1) are distinguished to permit the editing of gross outliers, while retaining the capability to accommodate TD variations during the March 1980 to May 1980 time period. Editing Mark 3 serves primarily to identify TDs which are affected by receiver cycle jumps and transmitter and control malfunctions.

2.2.4 Editing Mark 4: Manual Editing

Editing Mark 4 is employed to manually flag suspect data which are not flagged automatically by other editing marks. The large volume of data makes it impractical to employ the Test Director's Log for manual editing. Consequently, the only use made of Editing Mark 4 is to identify duplicate data which arise either in the transferral of tape cassette data to half-inch magnetic tape by the U.S. Coast Guard, or in the

*The mean of the high-density TD data for the entire year differs from this value by less than 0.05 μsec.

processing of the half-inch magnetic tapes by TASC. The absence of further manual editing does not detract from the data quality in view of the comprehensive automatic editing employed.

2.2.5 Editing Mark 5: Differential-Correction Indicator

Differential corrections are computed and included in the site data records to show the difference between measured SAM TDs and the Controlling Standard TD (the reference used for chain control). Differential corrections can be added to the measured site TDs in post-time to simulate perfect chain control. When site and SAM TDs are not measured at the same times, the SAM TDs are estimated by linear interpolation (Ref. 5). Care is taken to include the effects of LPAs and receiver averaging times ($\tilde{}$50 sec) in the interpolated TDs. An offset of 850 sec in the LC-204 recording times relative to the actual sampling times is also accounted for in this procedure.

Editing Mark 5 indicates the length of the interpolation interval used in the differential-correction computation (see Table 2.2-1). Intervals greater than a quarter of the diurnal cycle (6 hr) are judged to be excessive, because the linear approximation no longer holds. Table 2.2-1 indicates circumstances under which no differential correction can be computed. Noteworthy in this regard is the period from 22 January 1980 to 31 March 1980, for which LPAs were provided to TASC in hand-written form with time to the nearest minute, rather than on the CALOC system printout with time to the nearest second. Editing Mark 5 is set to "3" in this case because the accuracy of the LPA data has not been verified by TASC.

2.2.6 Editing Mark 6: Outlier Editing

Editing Mark 6 is employed to flag data which are inconsistent with the short-term behavior of the TD time series, but are not flagged by other editing marks. These outlying data represent isolated "events" caused by low signal-to-noise ratio, transmitter/receiver/control malfunctions, or anomalous propagation conditions. Although the outliers must be edited to permit an orderly analysis of typical TD variations, they are marked in the data base for use in possible future cause/effect studies.

Outliers are detected automatically by comparing each TD sample to a trend line fit to all data in a daily time window (Ref. 5). Samples which differ from the trend line by greater than 0.15 μsec are marked "5" or "6" as indicated in Table 2.2-1, and a new trend line is computed from the remaining samples. The samples are then compared to the refined trend line and marked "0" to "4" to indicate which 0.05-μsec error-bin they fall into (see Table 2.2-1). This procedure produces a histogram of TD errors relative to the trend line.

2.3 TD DATA INVENTORY

The operations involved in editing the TD data base for high-density analyses are summarized in Table 2.3-1. The editing mark values which define the data base are noted below:

- Editing Mark 1 = "X", "Y", or "Z": two TD time series are extracted for each site receiver and three for the SAM receiver
- Editing Mark 2 = "0": 87.7 to 98.4 percent of the data are associated with good signal quality

TABLE 2.3-1

SUMMARY OF EDITING OPERATIONS

SITE	RECEIVER TYPE/ NUMBER	TIME DIFFERENCE	TOTAL NUMBER OF SAMPLES	PERCENT OF DATA RETAINED AFTER EACH EDITING OPERATION			NUMBER OF RETAINED SAMPLES	STANDARD DEVIATIONS (μsec)
				SIGNAL-QUALITY CHECK	TOLERANCE CHECK	OUTLIER EDITING		
DeTour	LC-204/1	X	17,574	90.4	93.0	87.5	14,417	0.015
		Y	19,186	92.7	69.1	82.7	11,403	0.024
DeTour	LC-204/2	Y	20,432	93.1	98.6	96.3	17,910	0.020
		Z	19,047	91.0	97.1	95.6	16,995	0.020
Dunbar	BRN-5/1	X	21,772	98.2	98.3	95.3	20,037	0.023
		Y	21,843	98.4	98.5	89.2	18,873	0.031
Dunbar	LC-204/2	Y	20,219	91.9	98.6	96.0	17,593	0.019
		Z	16,983	92.1	98.4	95.3	14,670	0.020
Iroquois	LC-204/1	X	28,650	88.2	99.2	97.8	24,527	0.017
		Z	28,485	88.0	99.2	96.4	23,959	0.020
Iroquois	LC-204/2	Y	29,344	90.3	98.3	96.2	25,052	0.020
		Z	29,642	87.7	98.8	97.6	25,041	0.018
SAM	Austron/1	X	37,486	97.6	97.4	98.1	34,995	0.016
		Y	37,484	95.6	97.9	97.4	34,135	0.019
		Z	37,363	97.2	98.0	96.9	34,463	0.018

*Standard deviation of the differences between the retained Tb data and trend lines fit to daily data segments.

- Editing Mark 3 = "0": 93.0 to 99.2 percent of the data are within 1.0 μsec of the seasonal mean, except for TDY for DeTour/ LC-204/1* which exhibits numerous cycle jumps
- Editing Mark 4 = "0": duplicate data are ignored in the "Total Number of Samples" column in Table 2.3-1
- Editing Mark 5 = any value: differential corrections are not applied because of their small magnitude relative to site TD variations (see Section 3.2) and because they are not available for the entire year
- Editing Mark 6 = "0": 89.2 to 98.1 percent of the data are within 0.05 μsec of the daily trend lines used for outlier detection.

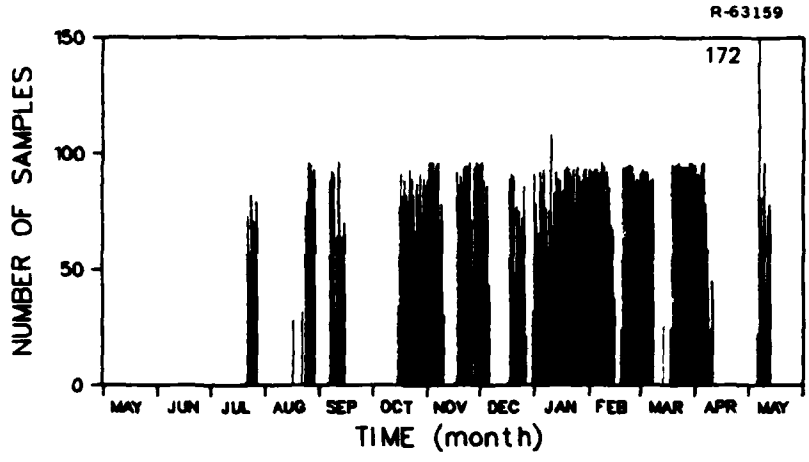
The number of samples retained after all editing operations ranges from 10,000 to 35,000 for the 15 TD time series (see Table 2.3-1).

The quality of the edited data base is judged to be excellent. Not only do all edited data lie within a ±0.05 μsec band centered on the daily trend line, but the standard deviations of the TD/trend line differences are between 0.015 μsec and 0.031 μsec (see Table 2.3-1). The short-term fluctuations are caused by atmospheric noise and the diurnal TD cycle, and are consistent with those measured in the laboratory (Ref. 7).

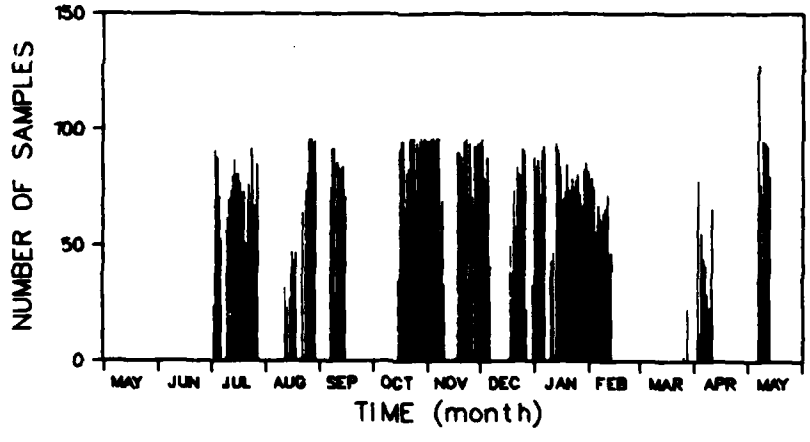
An inventory of the edited TD data is presented in Figs. 2.3-1 to 2.3-7, where the bars indicate the number of samples per day (nominally, 96). The large gaps which appear

---

*Each receiver is uniquely identified by site/receiver type/ receiver number.

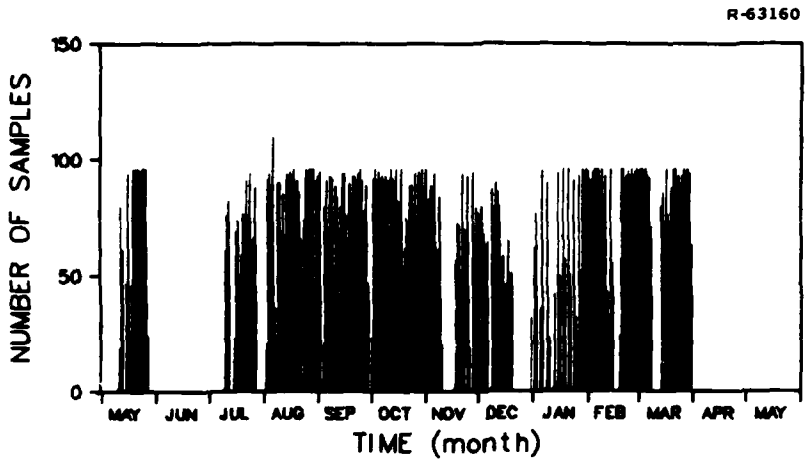


a) Time Difference X

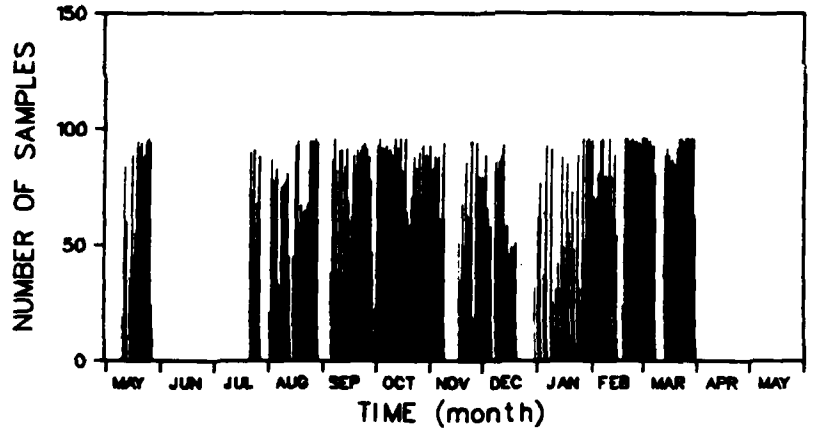


b) Time Difference Y

Figure 2.3-1 TD Data Inventory for DeTour/LC-204/1

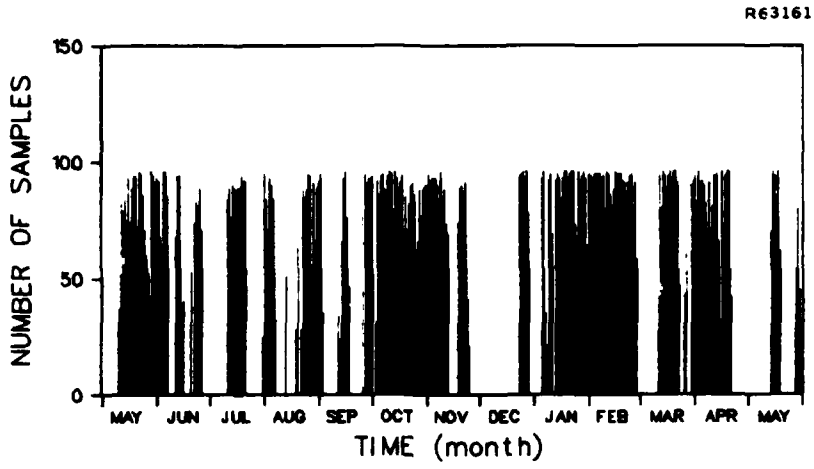


a) Time Difference Y

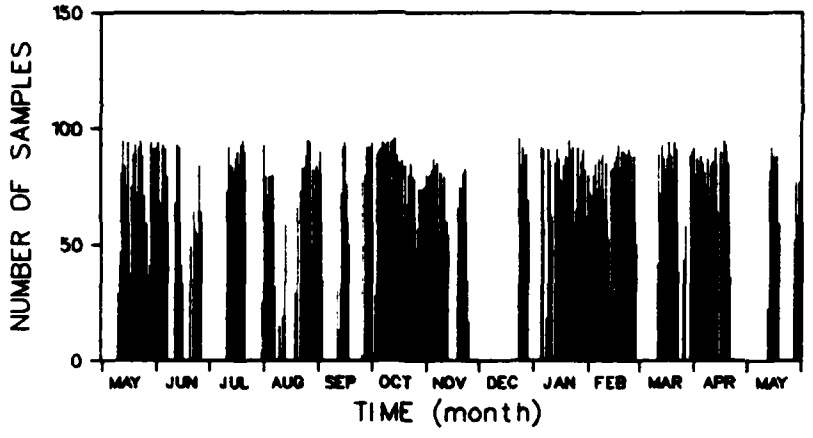


b) Time Difference Z

Figure 2.3-2 TD Data Inventory for DeTour/LC-204/2

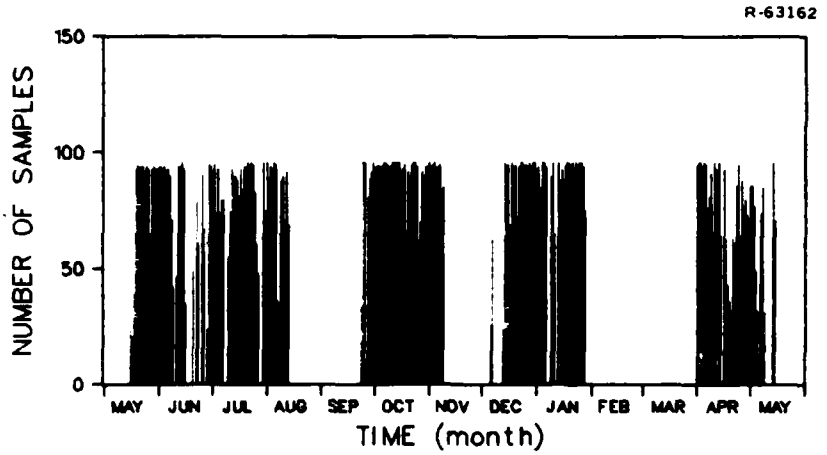


a) Time Difference X

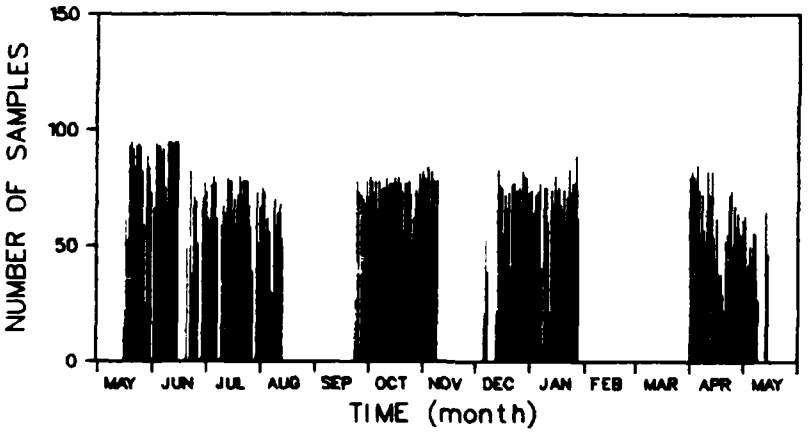


b) Time Difference Y

Figure 2.3-3 TD Data Inventory for Dunbar/BRN-5/1

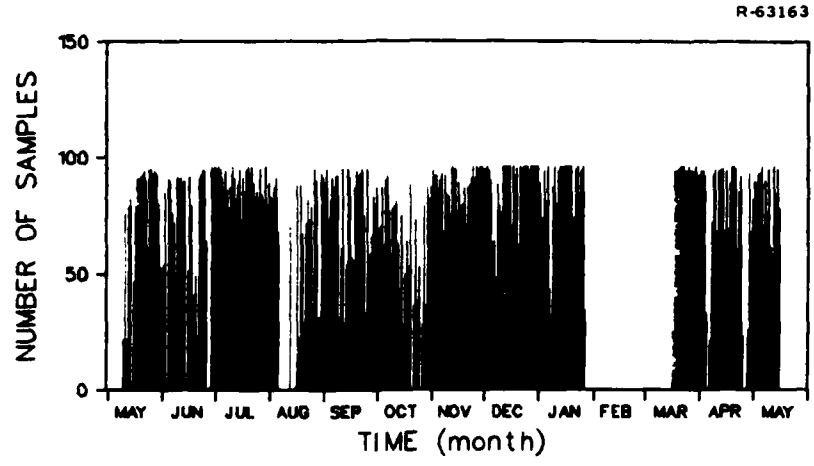


a) Time Difference Y

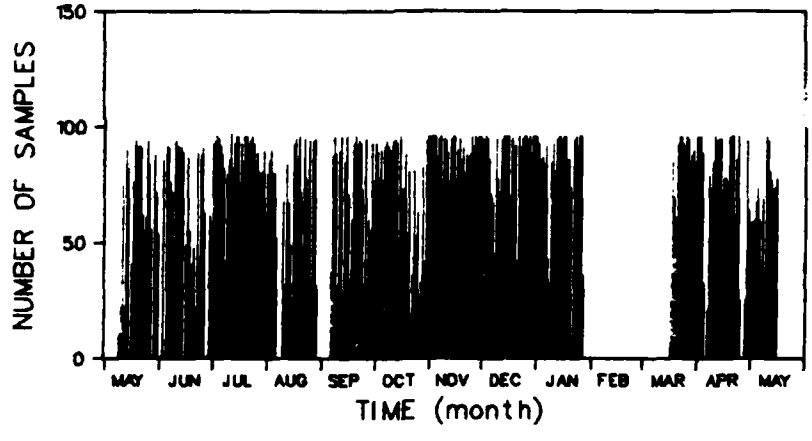


b) Time Difference Z

Figure 2.3-4 TD Data Inventory for Dunbar/LC-204/2

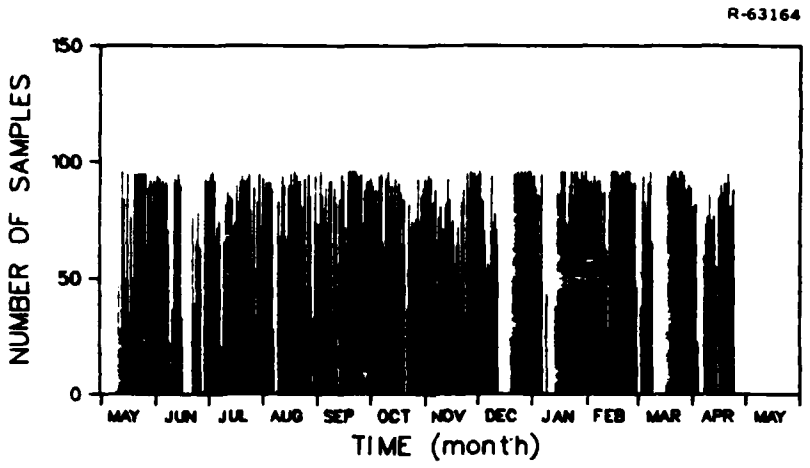


a) Time Difference X

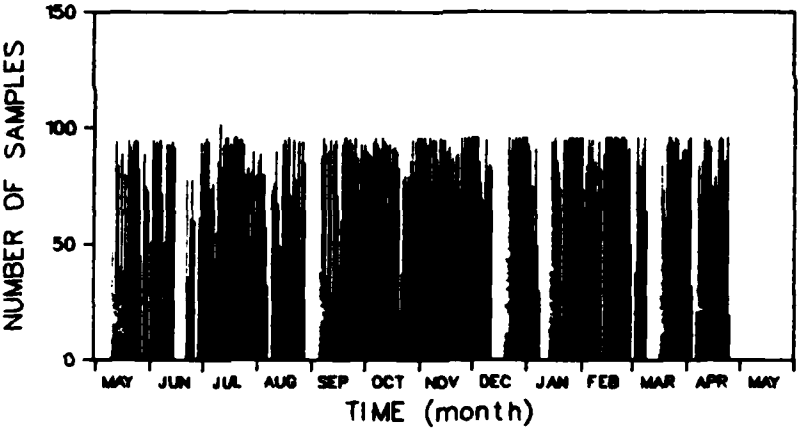


b) Time Difference Z

Figure 2.3-5 TD Data Inventory for Iroquois/LC-204/1

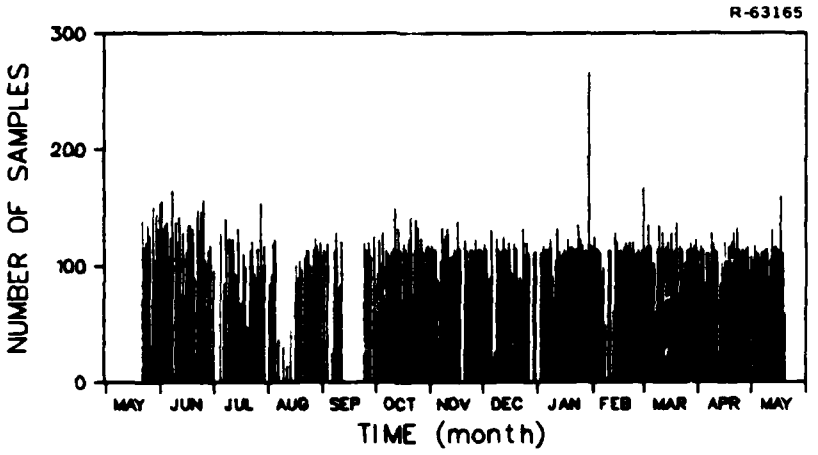


a) Time Difference Y

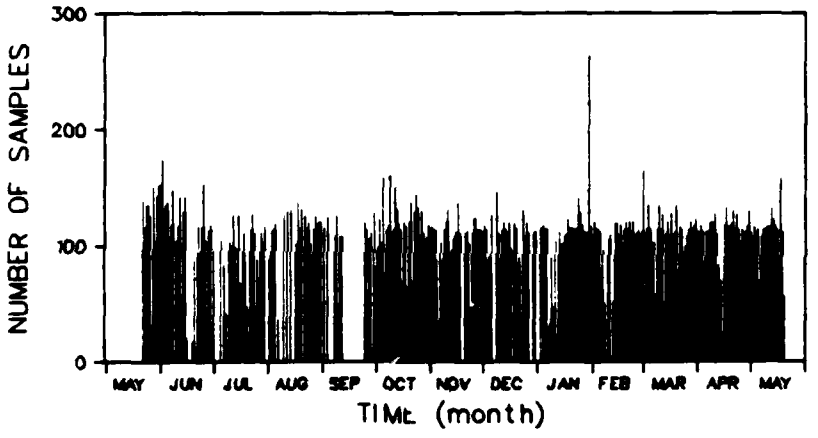


b) Time Difference Z

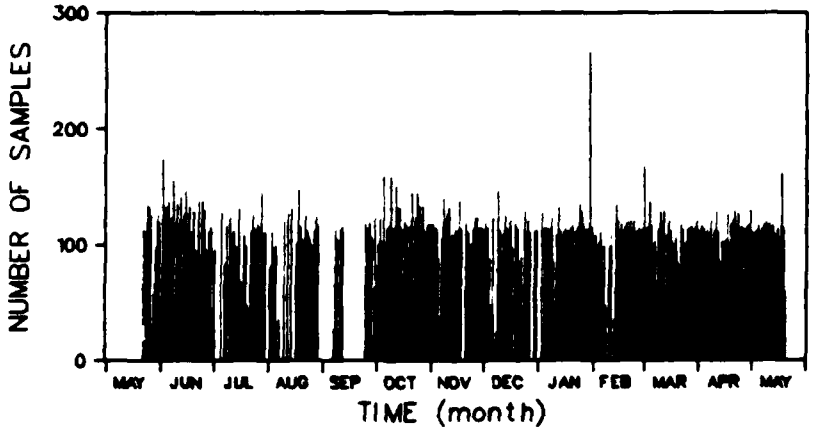
Figure 2.3-6 TD Data Inventory for Iroquois/LC-204/2



a) Time Difference X



b) Time Difference Y



c) Time Difference Z

Figure 2.3-7 TD Data Inventory for SAM/Austron/1

in many time series are associated with missing cassette tapes, rather than edited data. The U.S. Coast Guard low-density data can be used to fill these gaps and provide additional low-frequency (seasonal) detail. However, inclusion of low-density data is beyond the scope of the current effort and would not significantly affect the analysis results.

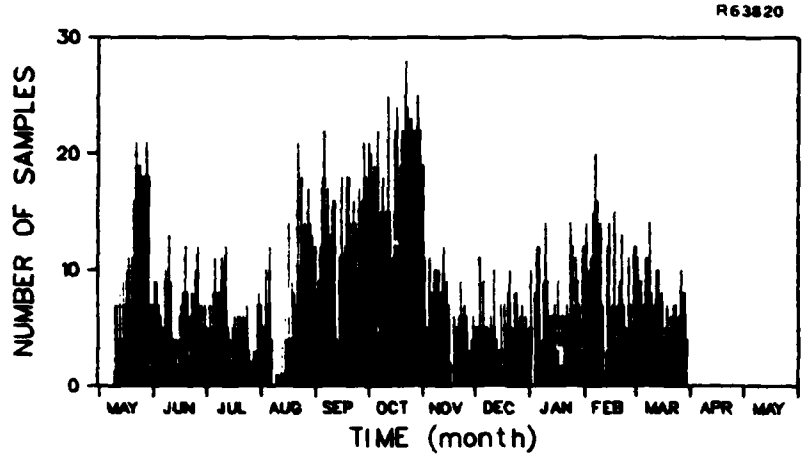
2.4 TOA DATA BASE

Master, Secondary X, and Secondary Y TOA data are measured with the BRN-5 receiver at the Dunbar site. An inspection of the TOA data shows that the clock was reset periodically to keep the master TOA near a value of 1000 μsec. The numerous TOA jumps introduced by this procedure make it infeasible to remove clock effects from the data. Identification of the jumps is further complicated by large gaps in the TOA time series, coincident with the TD time series gaps shown in Fig. 2.3-3.

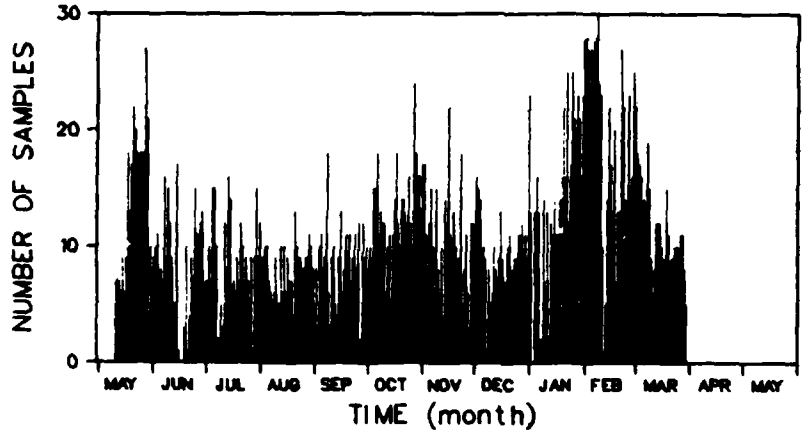
Because clock effects cannot be removed, the TOA data are not analyzed in the current study. TOA Editing Marks 1, 2, and 4 are set by the Data-Base Management Software, but the remaining editing marks require prior compensation for clock phase variations.

2.5 LPA DATA INVENTORY

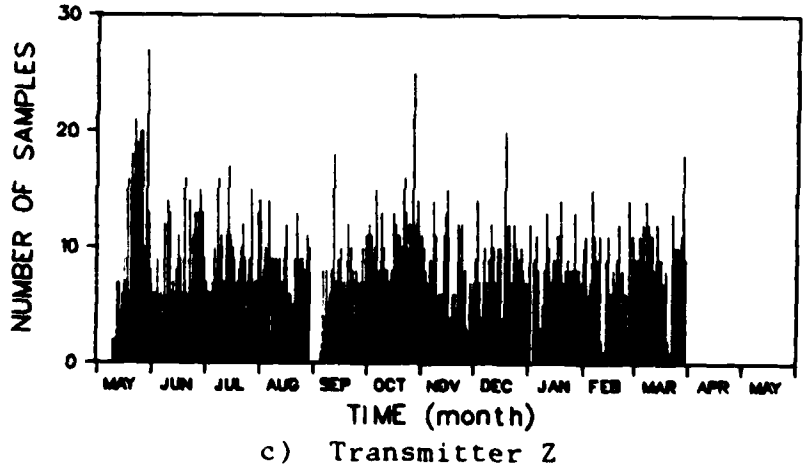
LPA data are manually entered into the data base by TASC, from the CALOC system printout. The number of LPA samples per day for each secondary transmitter is shown in Fig. 2.5-1. Approximately 10 LPAs per day, on the average, are required to satisfy the 0.015-μsec control tolerance.



a) Transmitter X



b) Transmitter Y



c) Transmitter Z

Figure 2.5-1 LPA Data Inventory

2.6 DATA-BASE TAPES DELIVERED TO U.S. COAST GUARD

The 46-megabyte St. Marys River Loran-C data base, with editing marks included, is delivered to the U.S. Coast Guard on three half-inch magnetic tapes (9-track, 800 BPI, ASCII code). The tapes are arranged as shown in Table 2.6-1, with one file for each receiver except the BRN-5, which requires a separate file for secondary and master records. The block size in each receiver file is 8190, which includes 63 records with 130 characters each. The block size for the LPA file is 8160, which includes 204 records with 40 characters each. The record formats are given in Appendices B and C.

TABLE 2.6-1

SUMMARY OF DATA-BASE TAPES DELIVERED TO U.S. COAST GUARD*

TAPE NUMBER	FILE NUMBER	SITE NUMBER†	RECEIVER TYPE	RECEIVER NUMBER	NUMBER OF DATA RECORDS
1	2	1	BRN5 SEC	1	2,589
1	3	1	BRN5 MAS	1	1,292
1	4	1	LC204	1	19,579
1	5	1	LC204	2	20,629
1	6	2	BRN5 SEC	1	48,017
1	7	2	BRN5 MAS	1	23,251
2	1	2	LC204	2	20,495
2	2	3	LC204	1	28,936
2	3	3	LC204	2	30,040
2	4	–	LPAs	–	9,517
3	1	8	AUSTRON	1	151,179

*This table is repeated on Tape 1/File 1.
†1 = DeTour, 2 = Dunbar, 3 = Iroquois, and 8 = SAM.

Each file is identified by lead and final records with the following formats:

```
***  BEGIN:  SITE=_  REC.TYPE=_____  REC.NUM=_  ***
***  END:    SITE=_  REC.TYPE=_____  REC.NUM=_  ***
```

The BRN-5 secondary and master files are further distinguished by the following second and next-to-last records:

```
***  BEGIN:  MASTER  ***
***  END:    MASTER  ***

***  BEGIN:  SECONDARY  ***
***  END:    SECONDARY  ***
```

In addition, each record has a unique "signature," consisting of the record number, site number, receiver type, and receiver number (see Appendix B).

3. QUANTIFICATION OF ST. MARYS RIVER LORAN-C TD GRID INSTABILITY

3.1 INTRODUCTION

The edited data base described in Section 2.3 is employed in this chapter to quantify TD grid instability in the St. Marys River Loran-C mini-chain. Quantification is based on the following non-parametric descriptions of the data:

- TD time series plots and related statistics to exhibit seasonal, monthly, and diurnal variations
- Autocorrelation and cross-correlation functions to identify TD/TD, TD/temperature, and TD/refractive index relationships
- Power spectral densities to examine the frequency content of the TD variations
- LPA statistics to quantify SAM TD variations in the case of no chain control
- Comparison of theoretical and measured TD variations to provide a basis for possible future studies.

The high-density analyses parallel the low-density analyses conducted by the U.S. Coast Guard, where possible.

3.2 TD TIME SERIES PLOTS AND RELATED STATISTICS

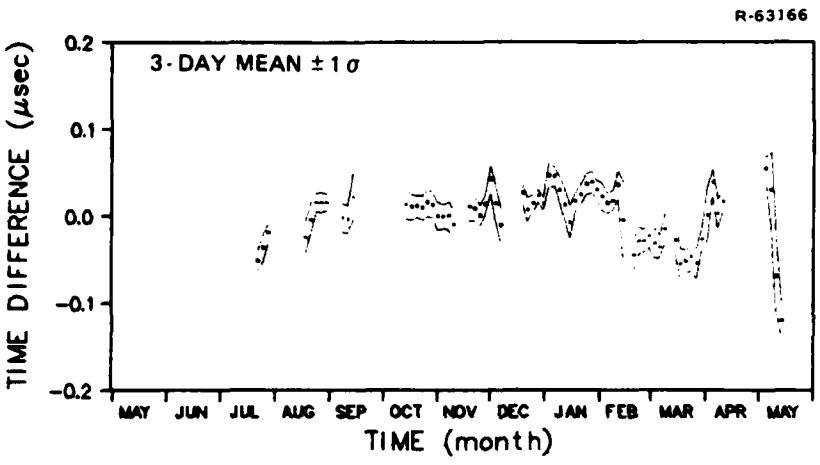
3.2.1 Seasonal Variations

Seasonal TD variations are quantified by the mean and standard deviation of the data in 3-day time windows (see

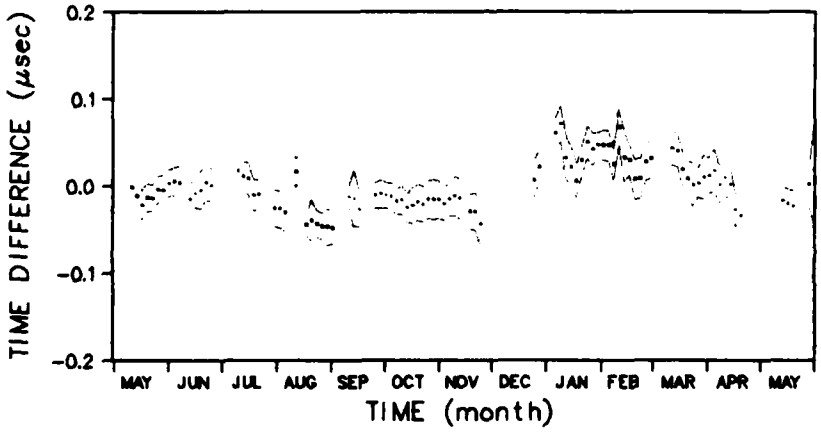
Figs. 3.2-1 to 3.2-4). In this study, seasonal variations are defined as the variation in the 3-day mean over the data collection period. The standard deviation gives an indication of shorter-term TD variations relative to the seasonal variations. To avoid misinterpretation of the results, no point is plotted for 3-day windows which contain fewer than 20 samples. The TD is shown relative to the average value of the time series, i.e., the mean of the 3-day means (see Table 3.2-1). The three redundant TDs -- TDY for DeTour/LC-204/1, TDY for Dunbar/BRN-5/1, and TDZ for Iroquois/LC-204/1 -- are not included here, but are discussed in Section 3.3.2.

An examination of Figs. 3.2-1 to 3.2-4 leads to the following conclusions:

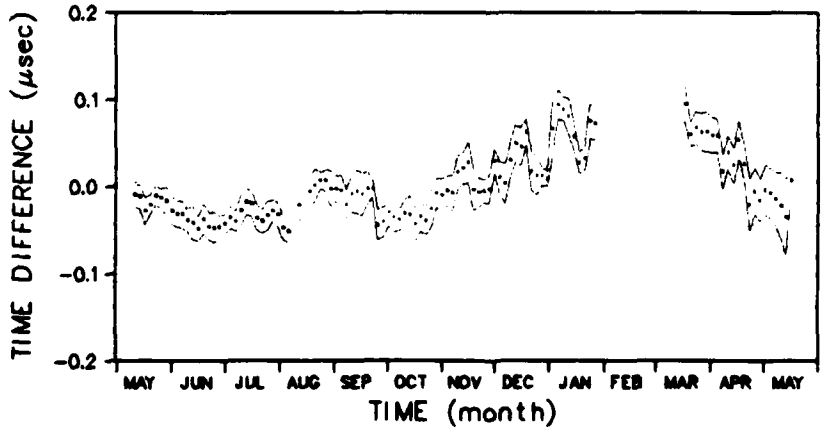
- Seasonal TD variations are less than 0.4 μsec peak-to-peak (p-p) at the DeTour, Dunbar, and Iroquois sites, consistent with previous observations (Refs. 2 and 3)
- TD values in May 1979 and May 1980 are approximately equal, suggesting that the seasonal meteorological cycle causes the variations
- TD variations during monthly periods are larger in the winter than in the summer, consistent with signal propagation theory (Refs. 3 and 9)
- The 3-day standard deviations (shown by dotted curves in Figs. 3.2-1 to 3.2-4) are less than 0.025 μsec, which is small relative to the variation of the 3-day means
- The standard deviation of the 3-day means (see Table 3.2-1) is larger for TDY than for TDX and TDZ, i.e., 0.069 μsec average compared to 0.032 μsec average
- SAM TD variations are less than 0.02 μsec p-p except for TDY in February (see Fig. 3.2-4), indicating that chain control tolerances are satisfied.



a) DeTour/LC-204/1

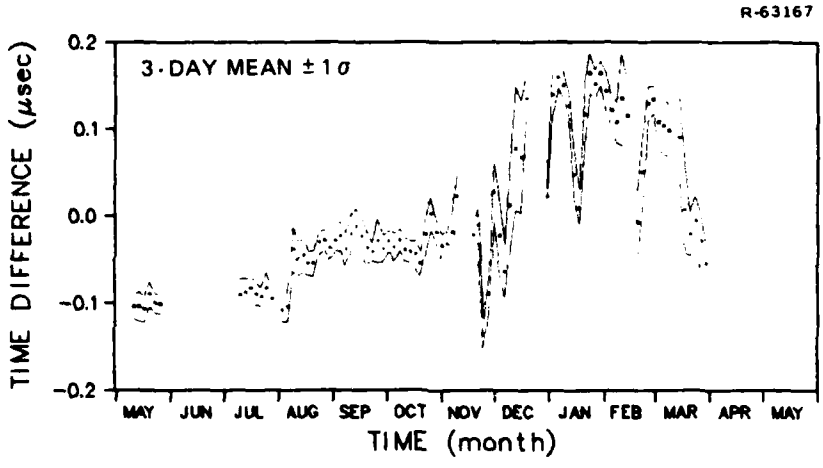


b) Dunbar/BRN-5/1

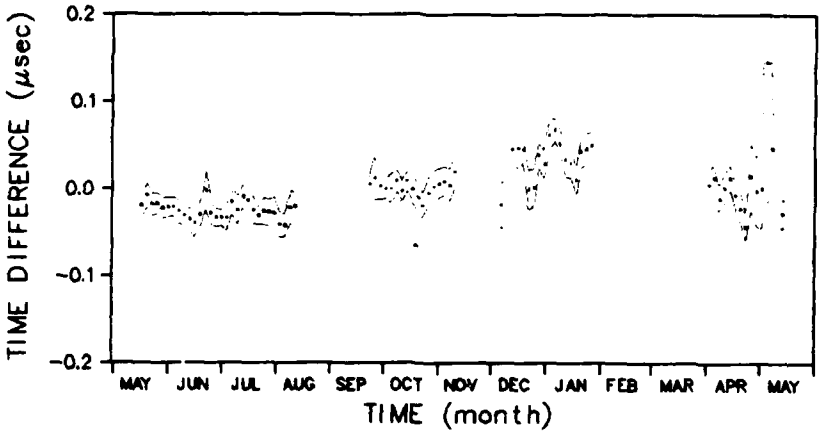


c) Iroquois/LC-204/1

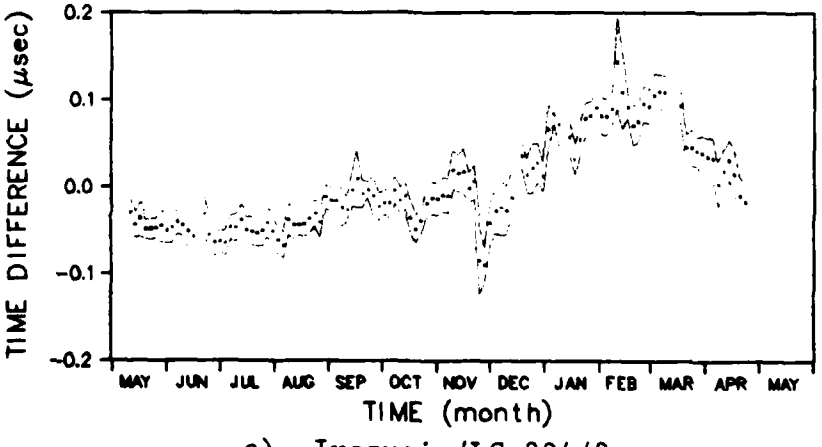
Figure 3.2-1 TDX Seasonal Time Series



a) DeTour/LC-204/2

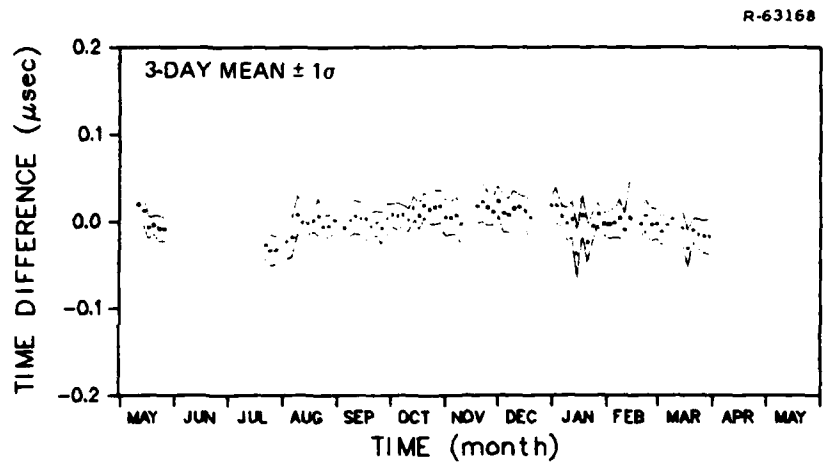


b) Dunbar/LC-204/2

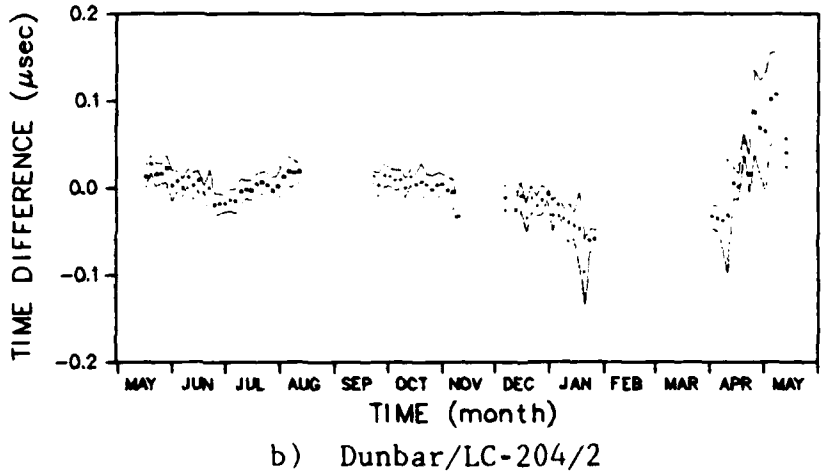


c) Iroquois/LC-204/2

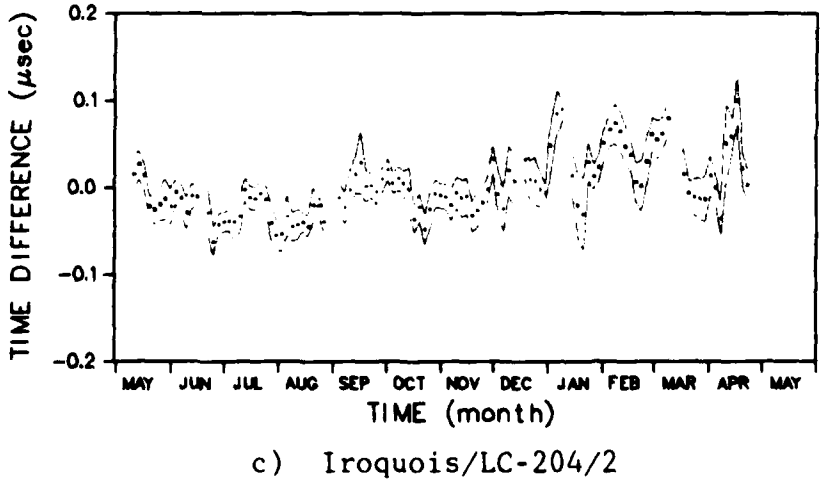
Figure 3.2-2 TDY Seasonal Time Series



a) DeTour/LC-204/2

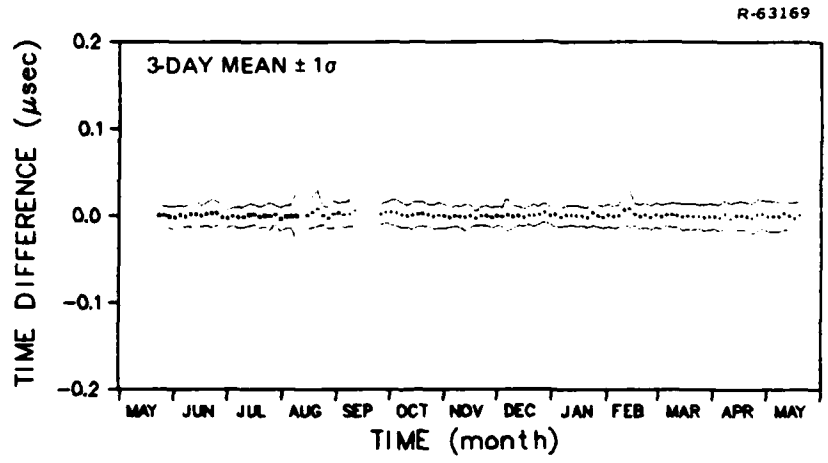


b) Dunbar/LC-204/2

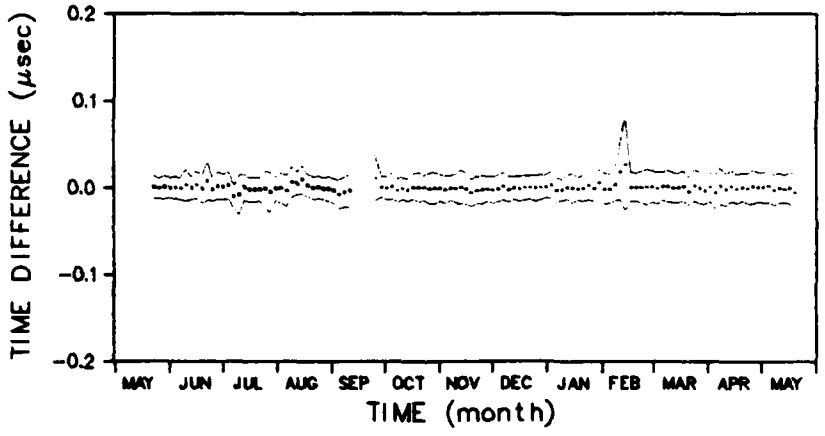


c) Iroquois/LC-204/2

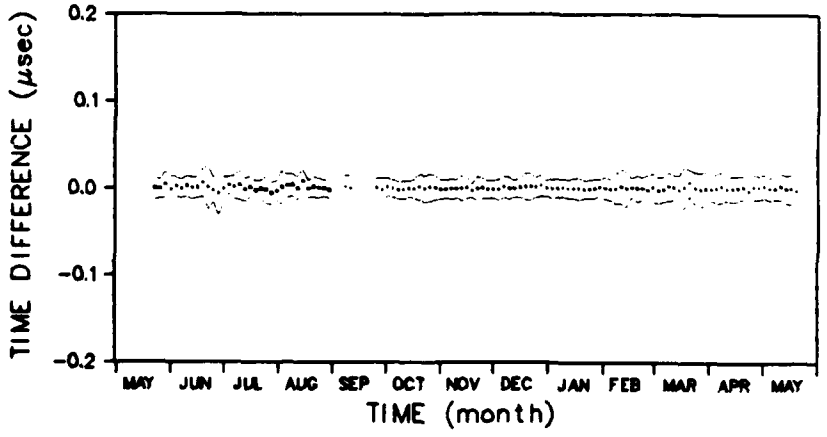
Figure 3.2-3 TDZ Seasonal Time Series



a) Time Difference X



b) Time Difference Y



c) Time Difference Z

Figure 3.2-4 SAM Seasonal Time Series

TABLE 3.2-1
SEASONAL TD STATISTICS

SITE	RECEIVER TYPE/ NUMBER	TIME DIFFERENCE	STATISTICS OF 3-DAY TD MEANS (μsec)		
			MEAN	STANDARD DEVIATION	PEAK-TO-PEAK
DeTour	LC-204/1	X	11328.261	0.032	0.174
		Y	22210.351	0.106	0.532
DeTour	LC-204/2	Y	22210.346	0.082	0.300
		Z	33416.693	0.013	0.061
Dunbar	BRN-5/1	X	11293.276	0.027	0.119
		Y	22363.361	0.045	0.180
Dunbar	LC-204/2	Y	22363.369	0.032	0.189
		Z	33290.870	0.033	0.204
Iroquois	LC-204/1	X	11325.374	0.037	0.146
		Z	33156.894	0.044	0.235
Iroquois	LC-204/2	Y	22413.893	0.052	0.232
		Z	33156.915	0.034	0.162
SAM	Austron/1	X	11259.695	0.002	0.013
		Y	22363.866	0.005	0.037
		Z	33200.397	0.003	0.015

The seasonal component of TD variations dominates the monthly and diurnal components, as expected for Loran-C groundwave propagation.

3.2.2 Monthly Variations

The distinct difference between summer and winter TD variations is analyzed by focusing on the months of July and January. Monthly TD variations are quantified by the mean and standard deviation of the data in 6-hr time windows (see Figs. 3.2-5 to 3.2-8 for July and Figs. 3.2-9 to 3.2-12 for January). No point is plotted for 6-hr windows which contain fewer than 10 samples.

An examination of the monthly time series leads to the following conclusions:

- TD variations are less than 0.10 μsec p-p for July, but as large as 0.20 μsec p-p for January
- TDs often change very abruptly in January, -- e.g., 0.10 μsec during a one- or two-day period
- Diurnal variations are smaller in July than in January, but represent a greater proportion of the overall monthly variation in July
- The 6-hr standard deviations are small relative to the variation of the 6-hr means
- The chain is controlled more effectively by the SAM in January than in July (compare Figs. 3.2-8 and 3.2-12).

Confirmation of the expected differences between summer and winter TD variations is an important contribution of the St. Marys River Loran-C data collection/analysis effort.

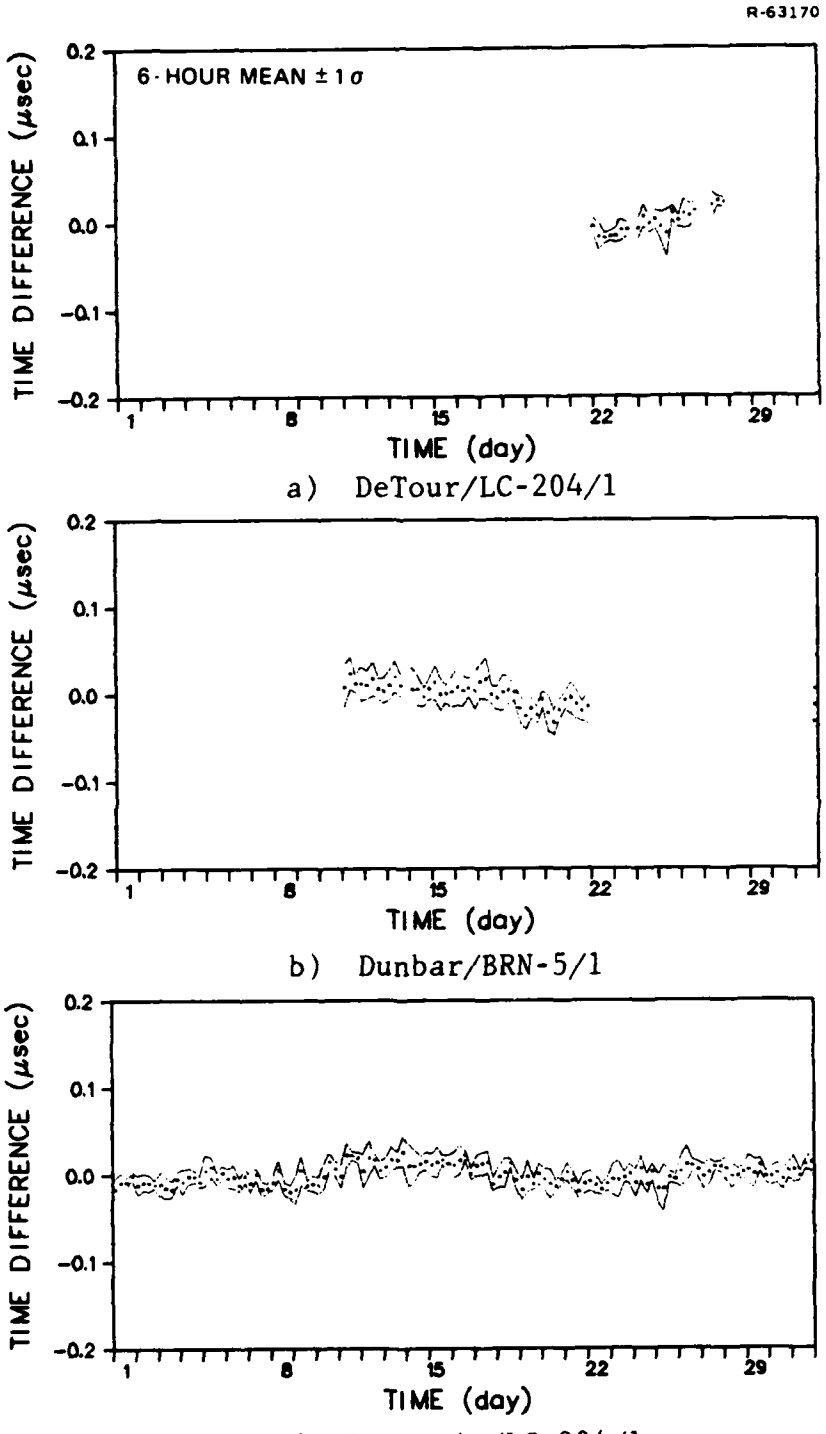
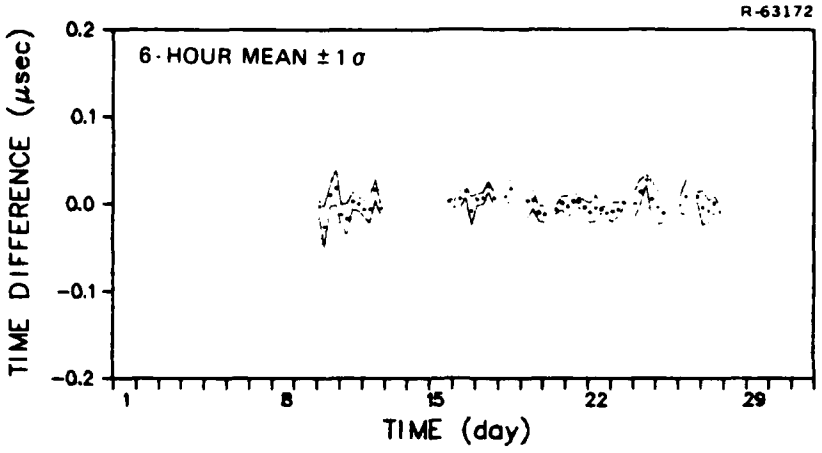
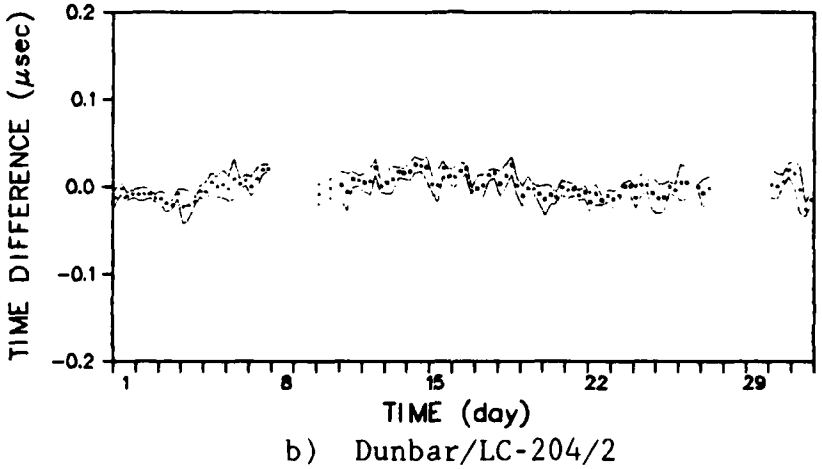


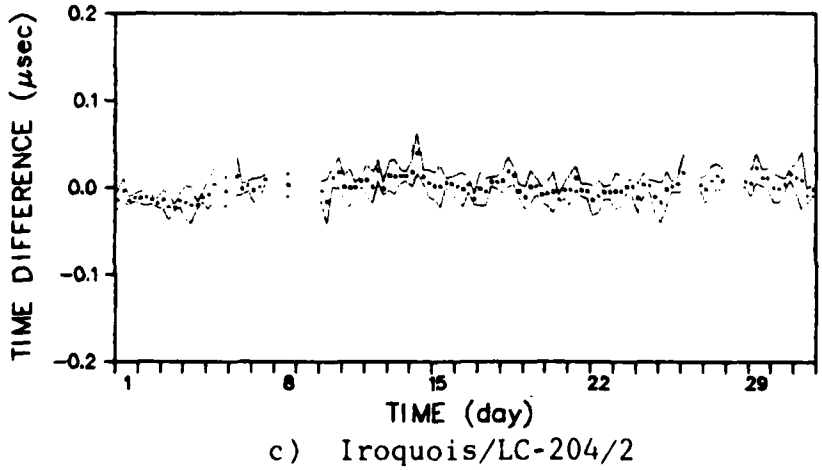
Figure 3.2-5 TDX Monthly Time Series for July



a) DeTour/LC-204/2

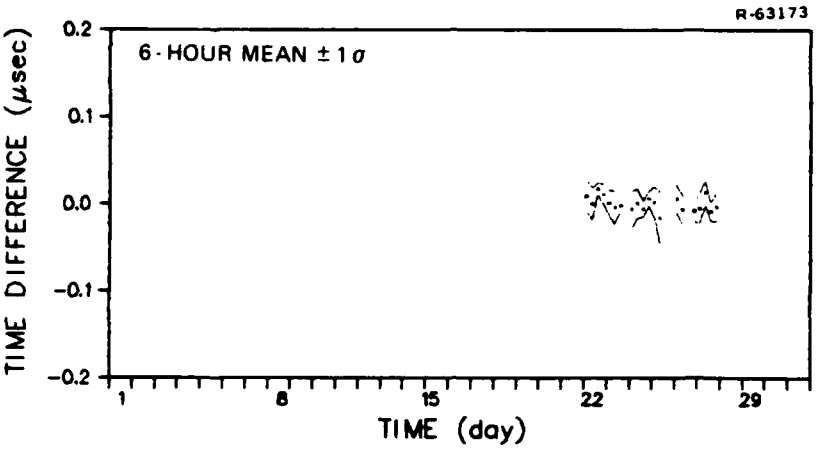


b) Dunbar/LC-204/2

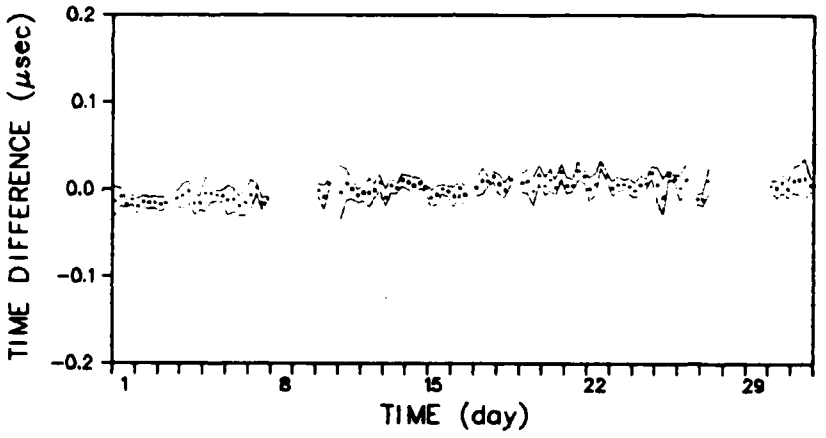


c) Iroquois/LC-204/2

Figure 3.2-6 TDY Monthly Time Series for July



a) DeTour/LC-204/2



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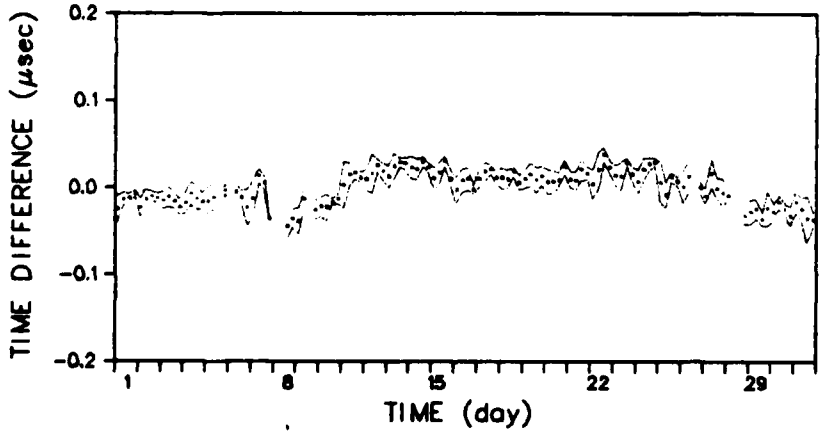
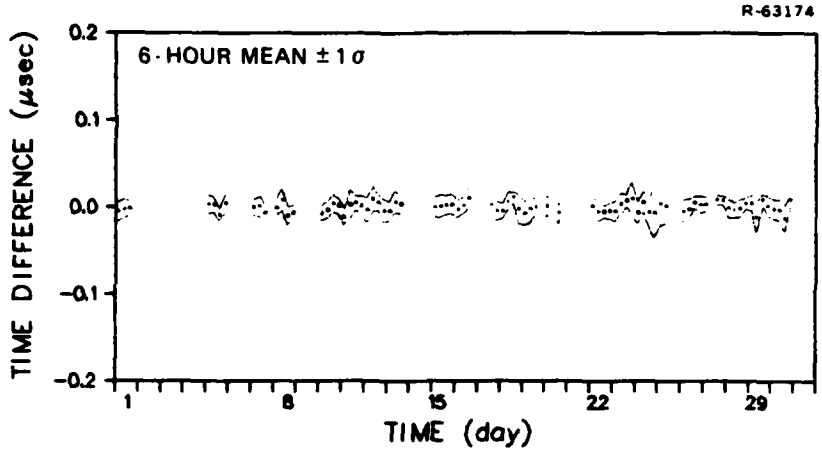
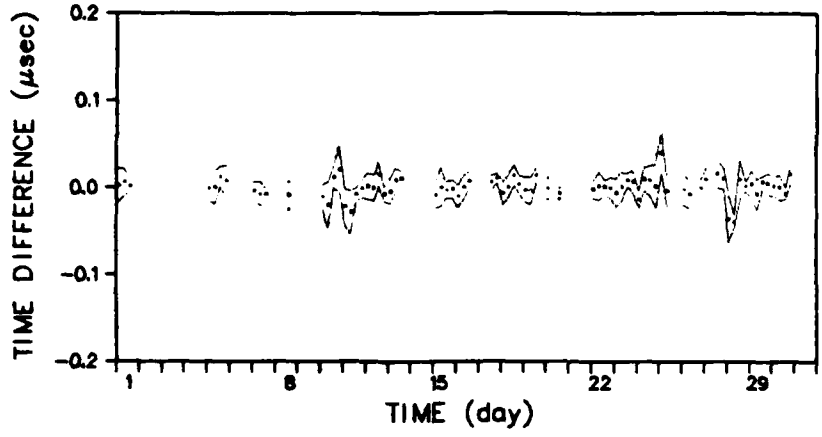


c) Iroquois/LC-204/2

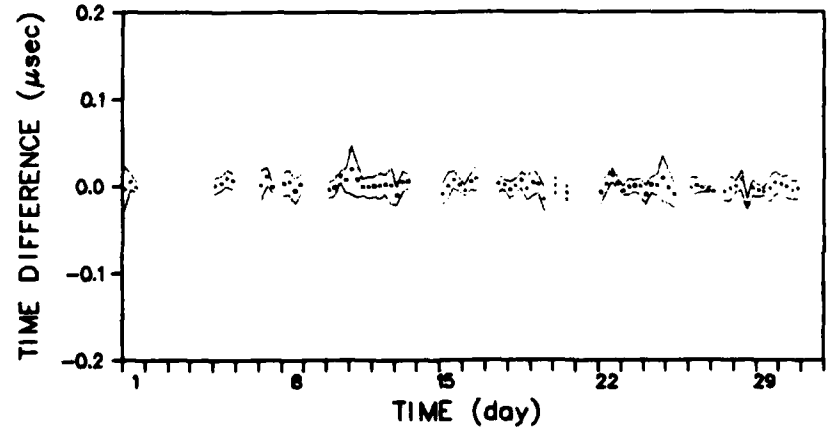
Figure 3.2-7 TDZ Monthly Time Series for July



a) Time Difference X

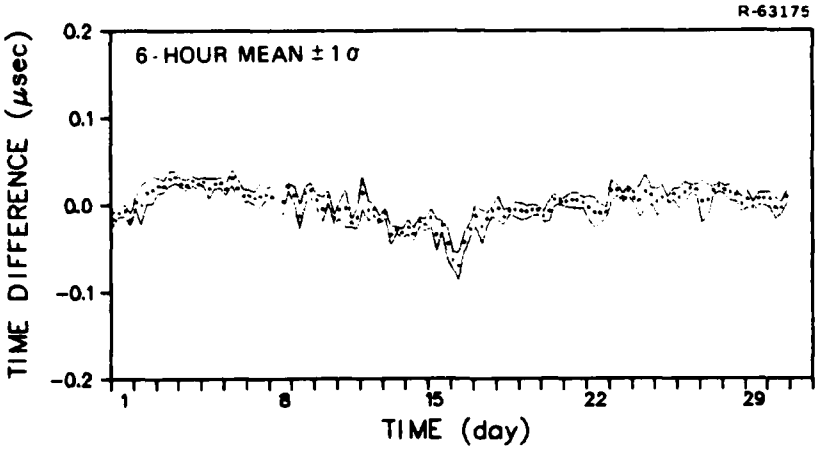


b) Time Difference Y

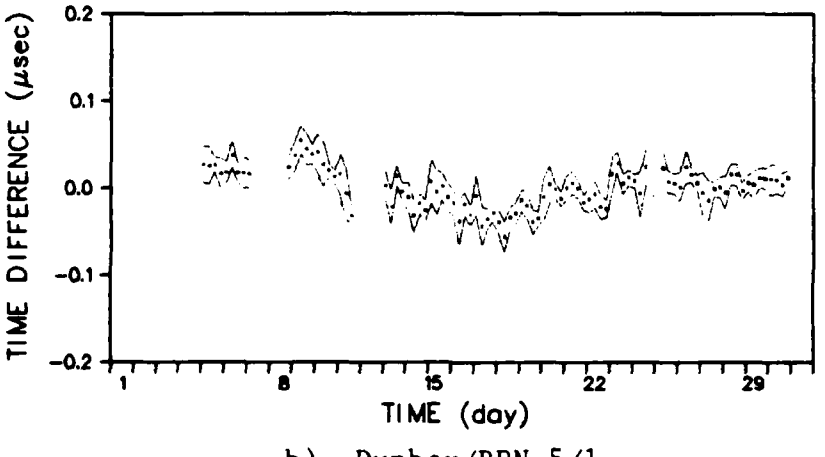


c) Time Difference Z

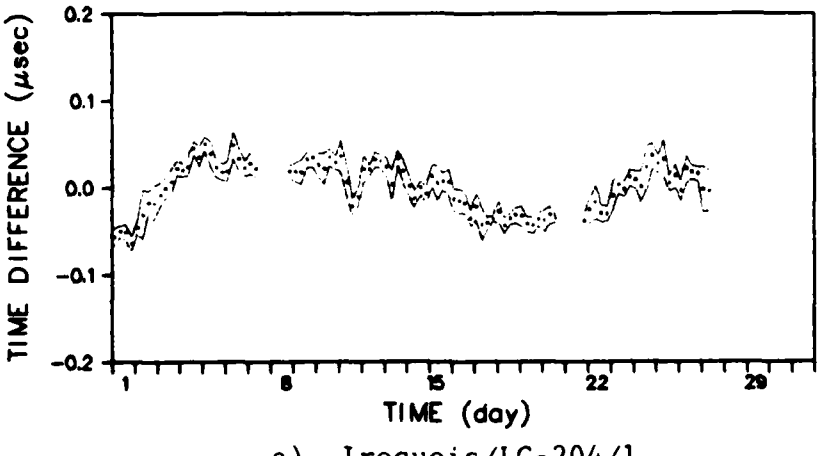
Figure 3.2-8 SAM Monthly Time Series for July



a) DeTour/LC-204/1

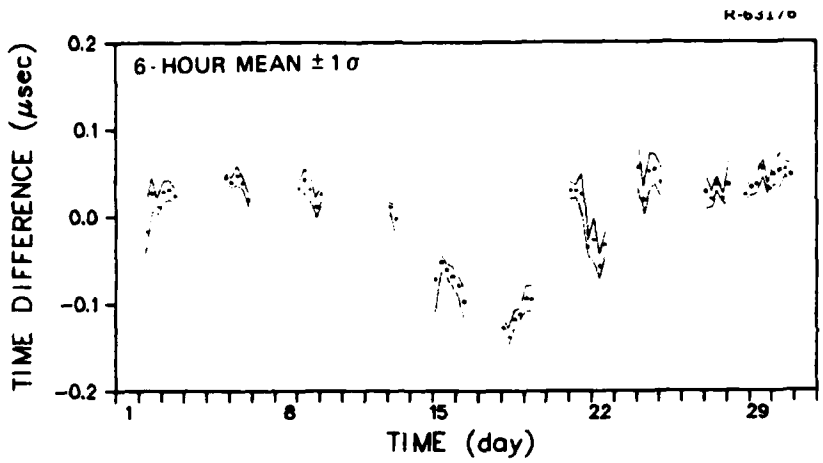


b) Dunbar/BRN-5/1

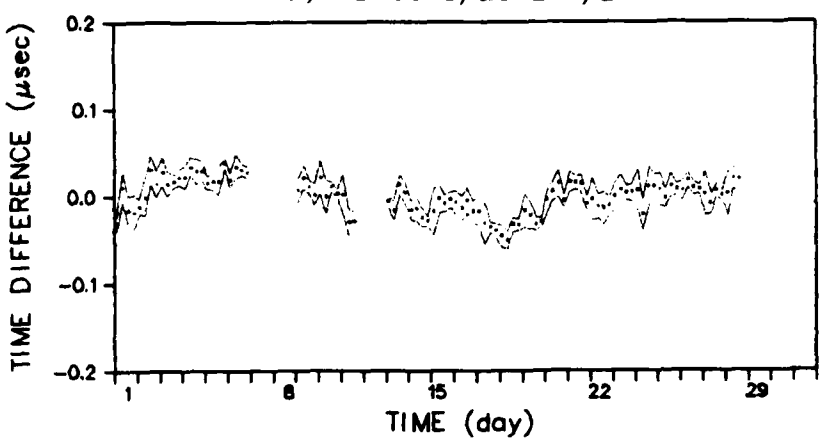


c) Iroquois/LC-204/1

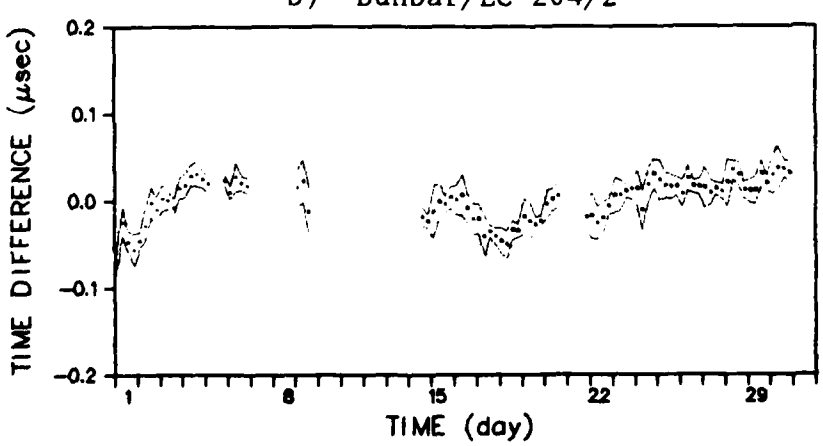
Figure 3.2-9 TDX Monthly Time Series for January



a) DeTour/LC-204/2

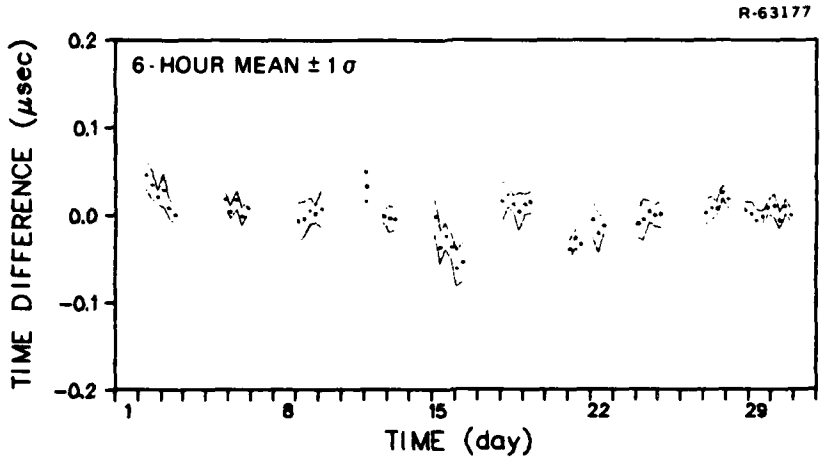


b) Dunbar/LC-204/2

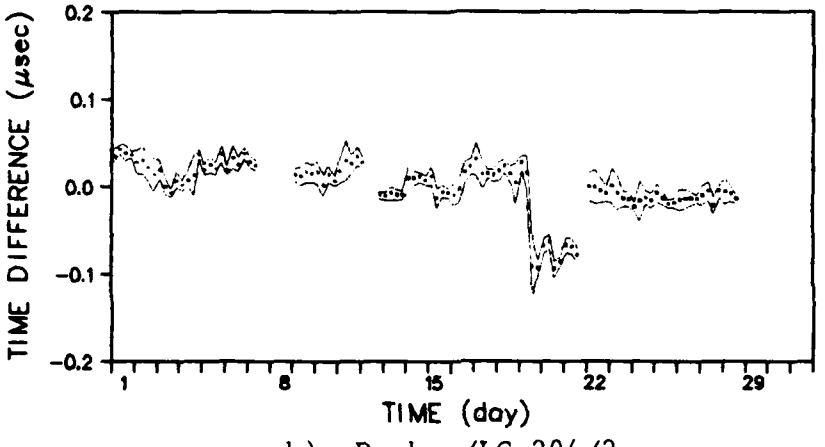


c) Iroquois/LC-204/2

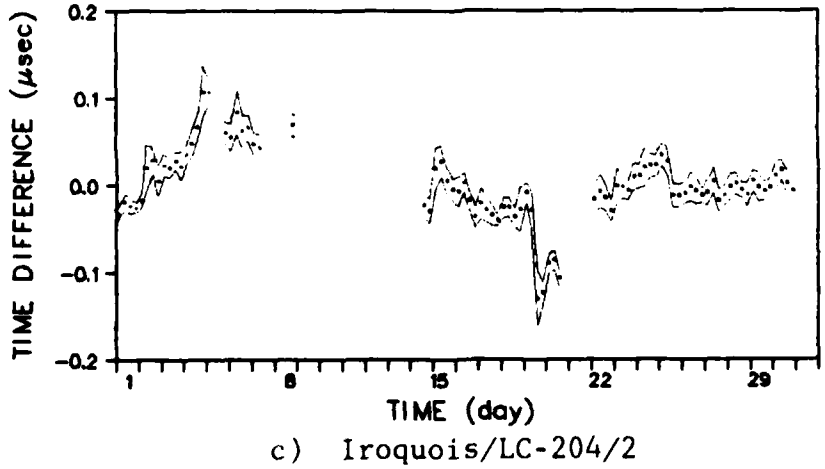
Figure 3.2-10 TDY Monthly Time Series for January



a) DeTour/LC-204/2

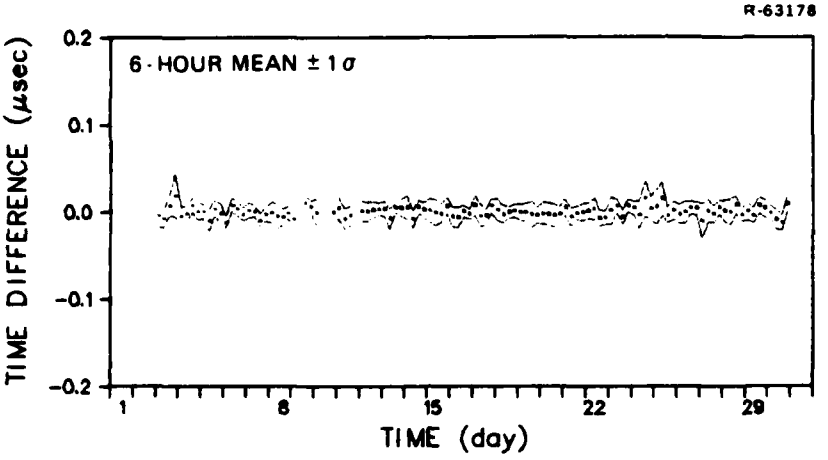


b) Dunbar/LC-204/2

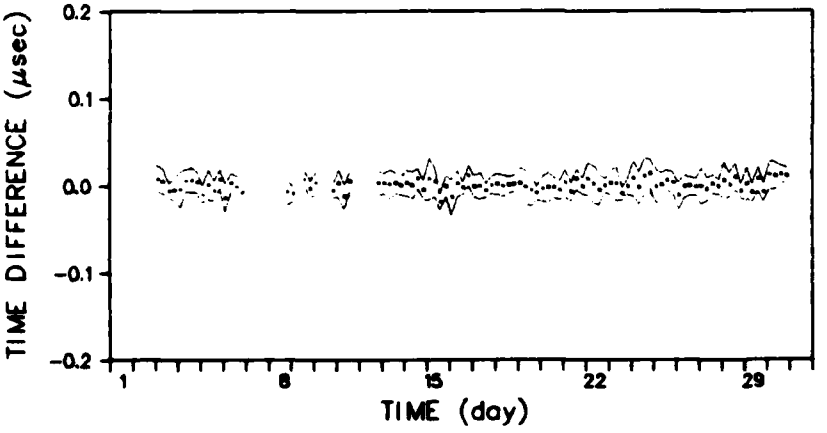


c) Iroquois/LC-204/2

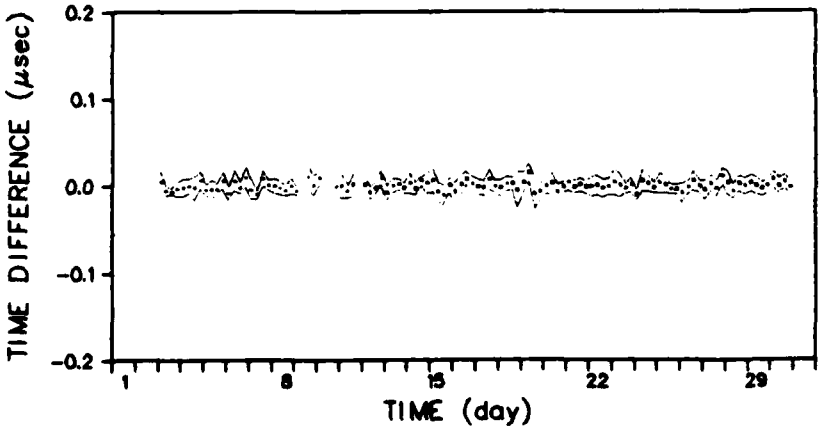
Figure 3.2-11 TDZ Monthly Time Series for January



a) Time Difference X



b) Time Difference Y



c) Time Difference Z

Figure 3.2-12 SAM Monthly Time Series for January

3.2.3 Diurnal Variations

Although diurnal variations are small compared to longer-term TD variations, their magnitude is important in selecting pattern monitor sampling rates and user update rates for differential Loran-C. The diurnal TD variations for July and January are analyzed separately herein, using the following procedure:

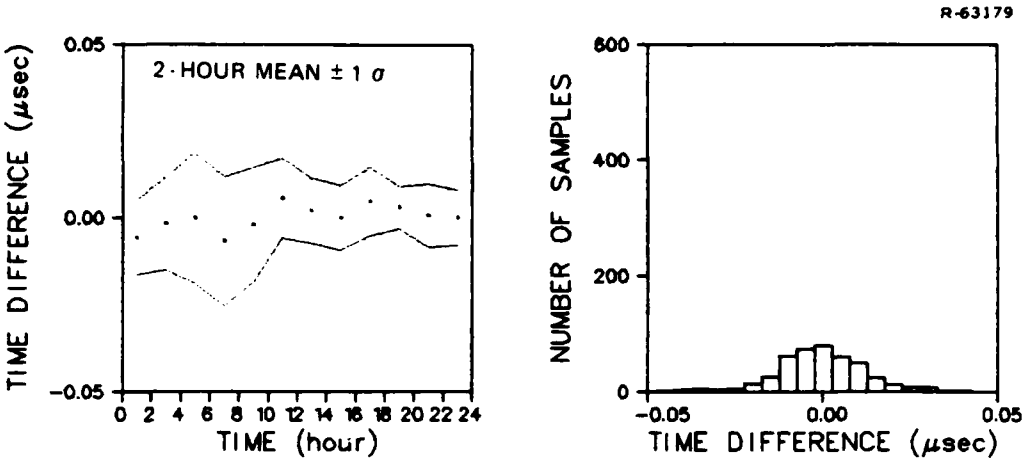
- Sort the data by day and subtract the daily mean to form TD residuals, thus removing the day-to-day variation
- Sort the TD residuals by time-of-day, irrespective of day-of-month, and compute the mean and standard deviation of the residuals in 2-hr time windows (the mean is the diurnal cycle)
- Construct a histogram of the differences between the residuals and the diurnal cycle.

The resulting diurnal cycles and histograms are presented in Figs. 3.2-13 to 3.2-15 for July and in Figs. 3.2-16 to 3.2-18 for January.*

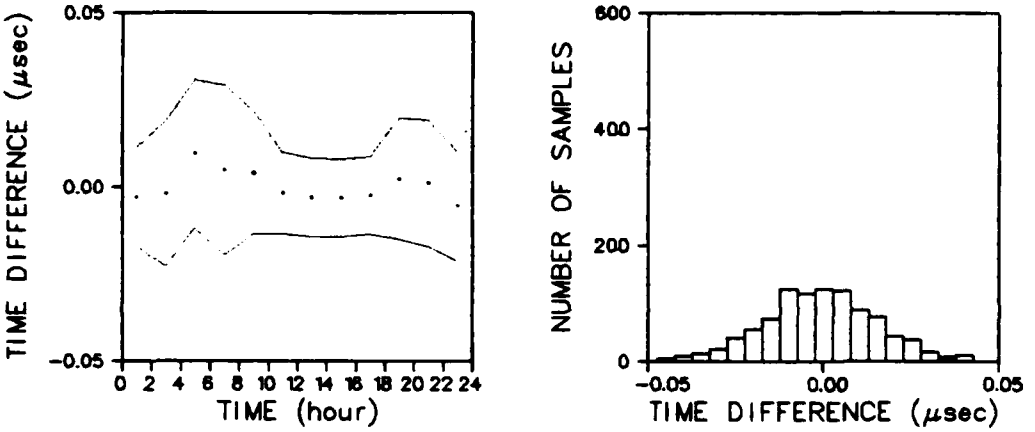
An examination of these results leads to the following conclusions:

- The diurnal cycles are small, generally less than 0.02 μsec p-p

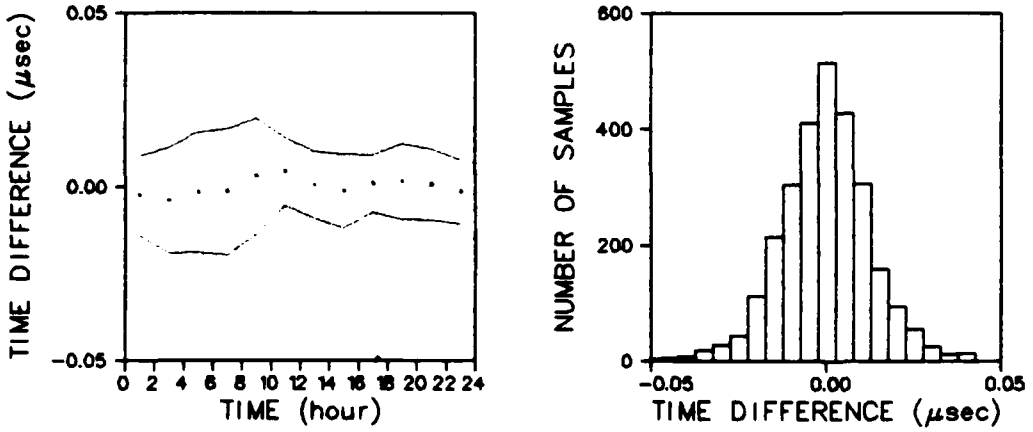
*The time shown is Greenwich Mean Time (GMT), where 0 hours GMT is 7 p.m. Sault Sainte Marie local time.



a) DeTour/LC-204/1

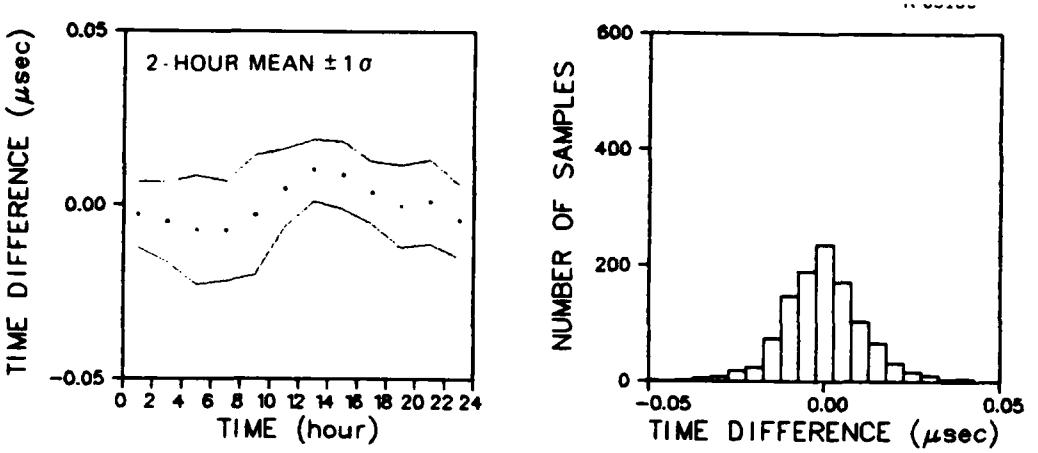


b) Dunbar/BRN-5/1

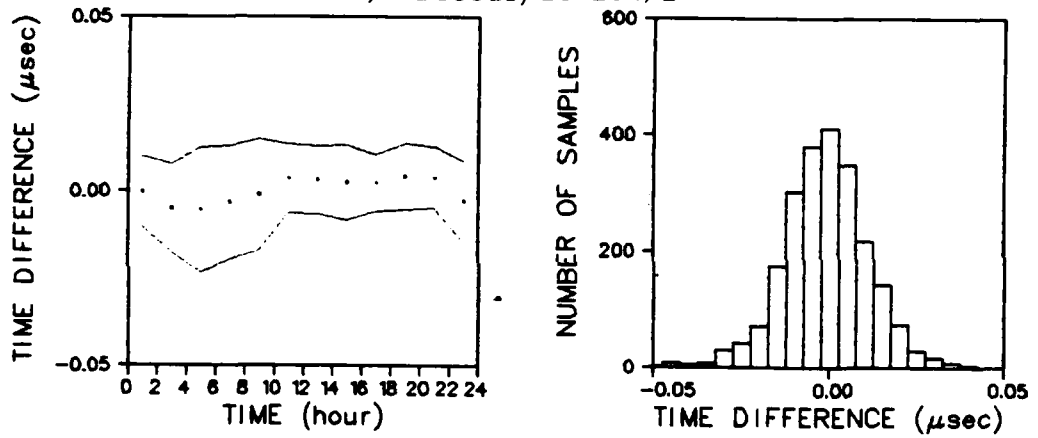


c) Iroquois/LC-204/1

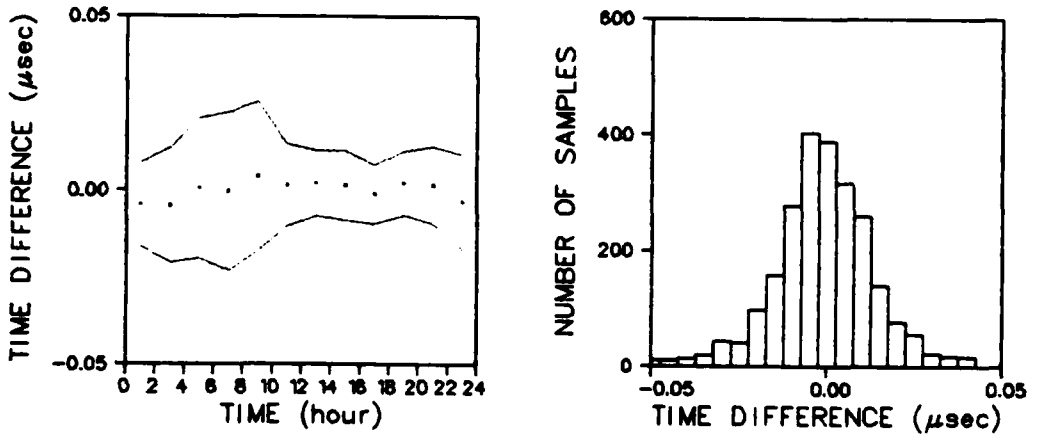
Figure 3.2-13 TDX Diurnal Cycles and Histograms for July



a) DeTour/LC-204/2

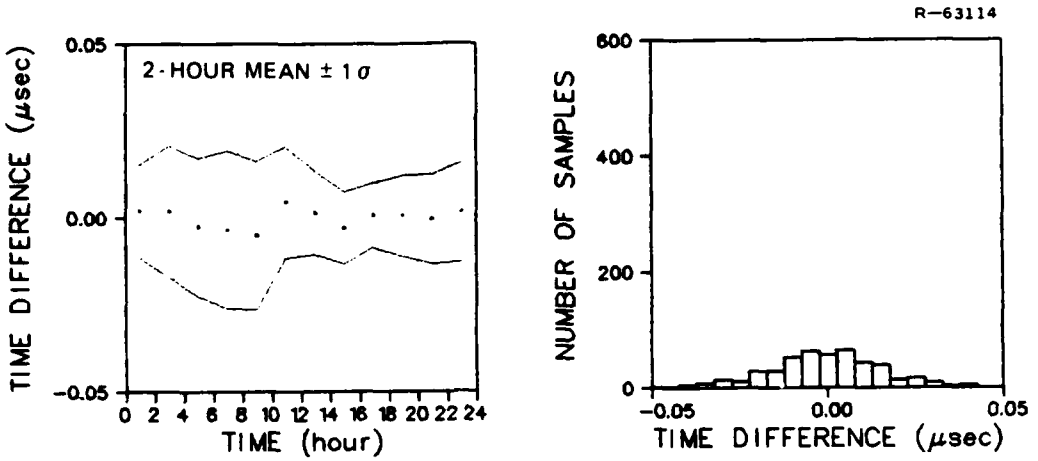


b) Dunbar/LC-204/2

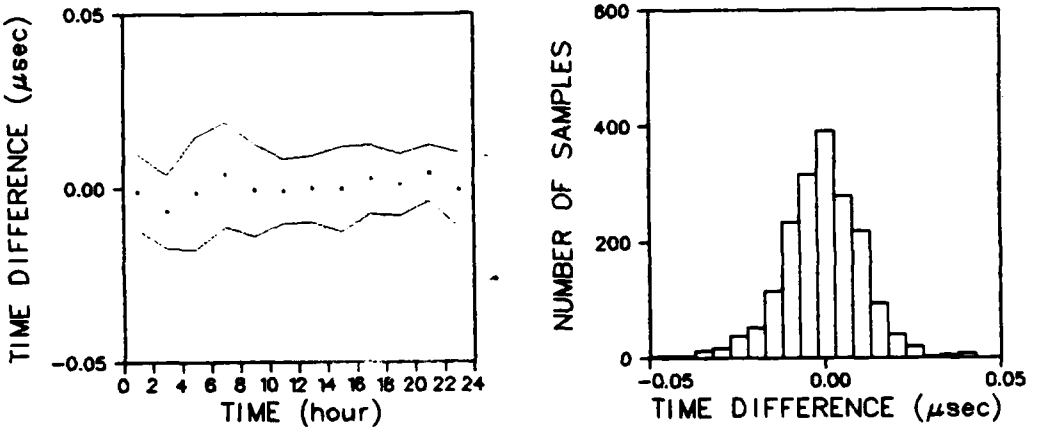


c) Iroquois/LC-204/2

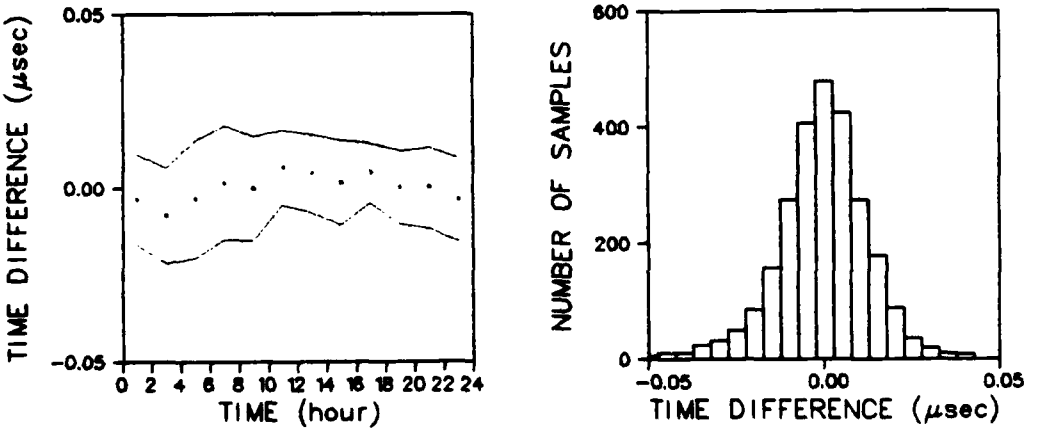
Figure 3.2-14 TDY Diurnal Cycles and Histograms for July



a) DeTour/LC-204/2

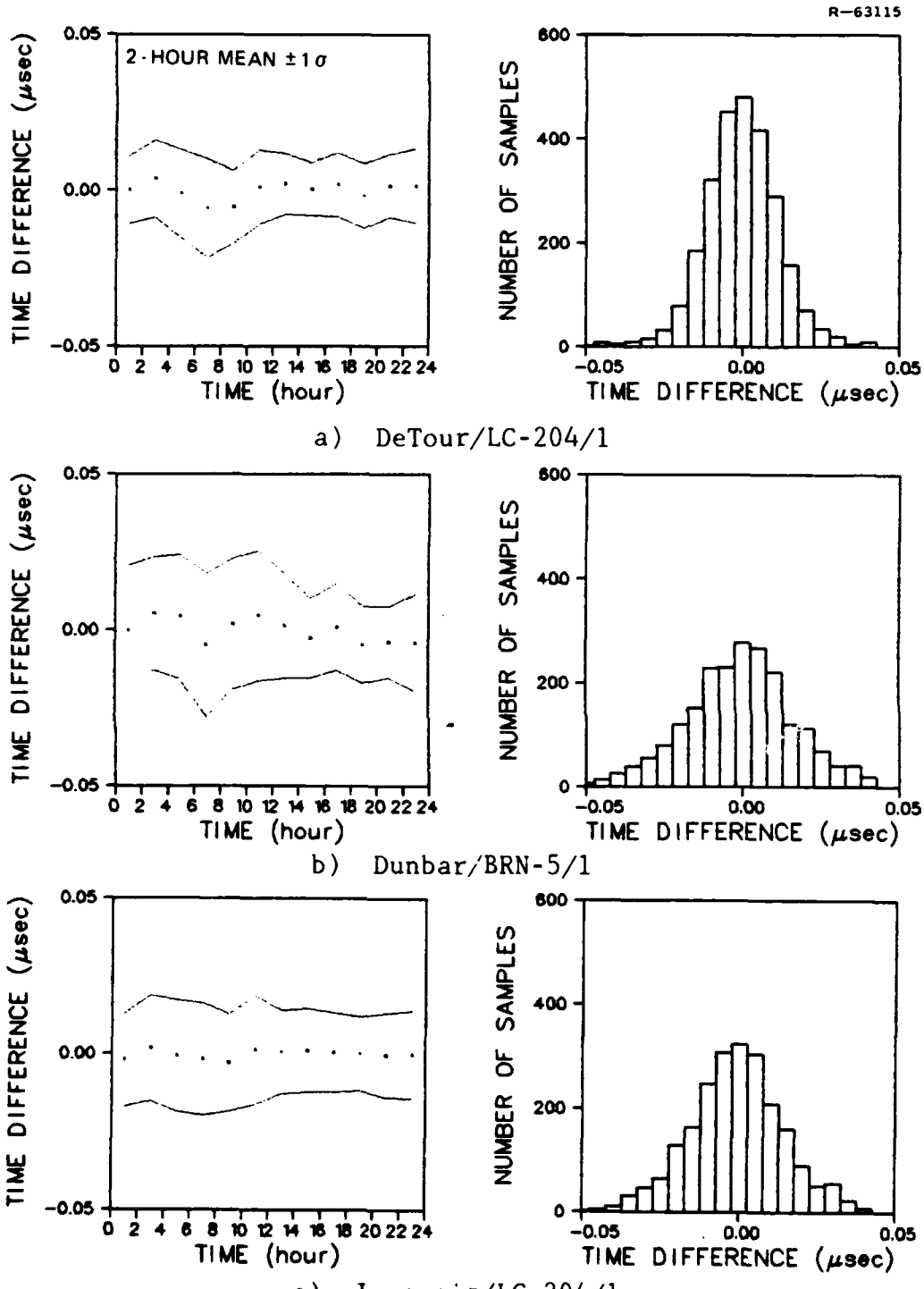


b) Dunbar/LC-204/2



c) Iroquois/LC-204/2

Figure 3.2-15 TDZ Diurnal Cycles and Histograms for July



a) DeTour/LC-204/1

b) Dunbar/BRN-5/1

c) Iroquois/LC-204/1

Figure 3.2-16 TDX Diurnal Cycles and Histograms for January

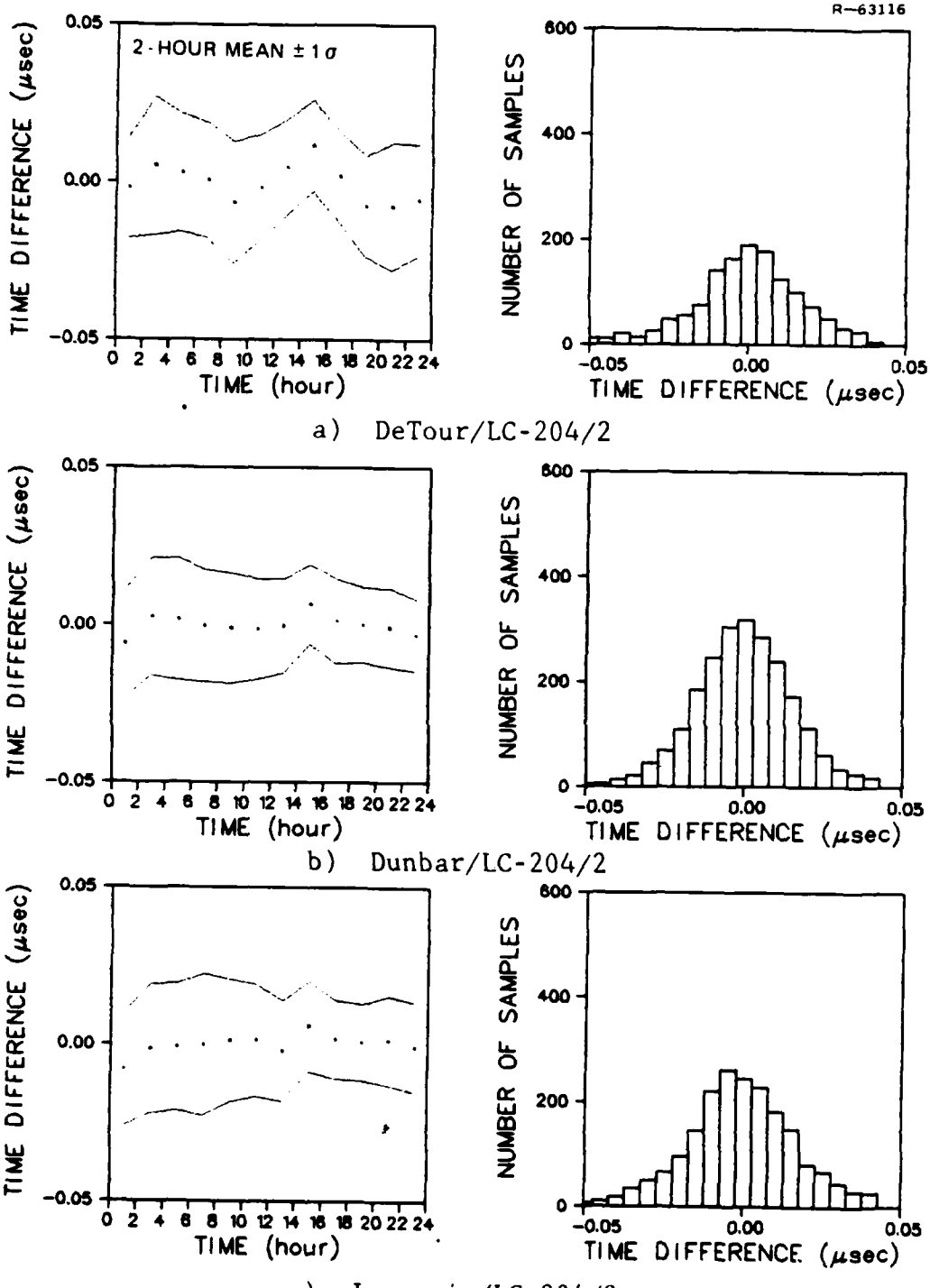
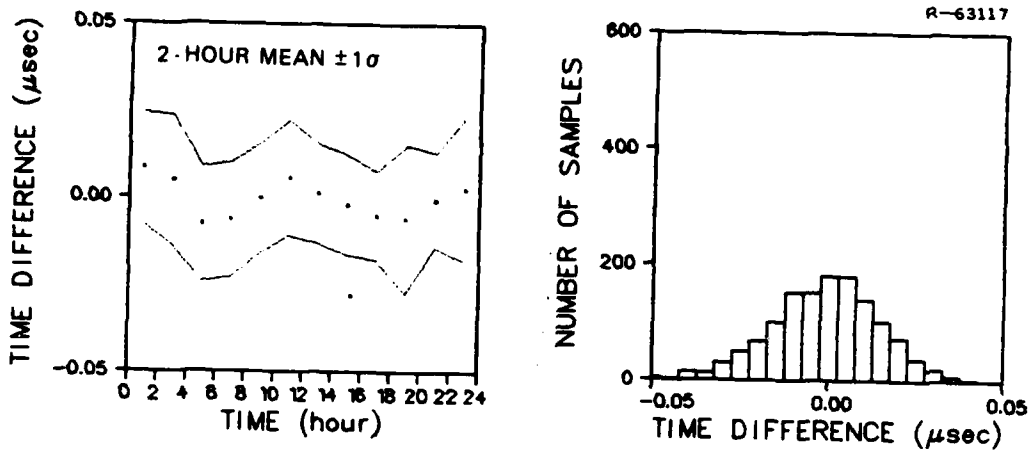
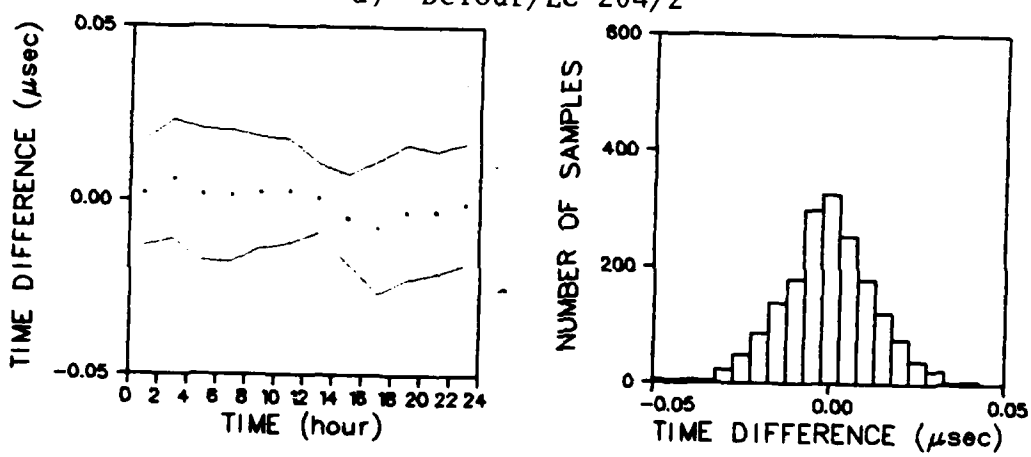


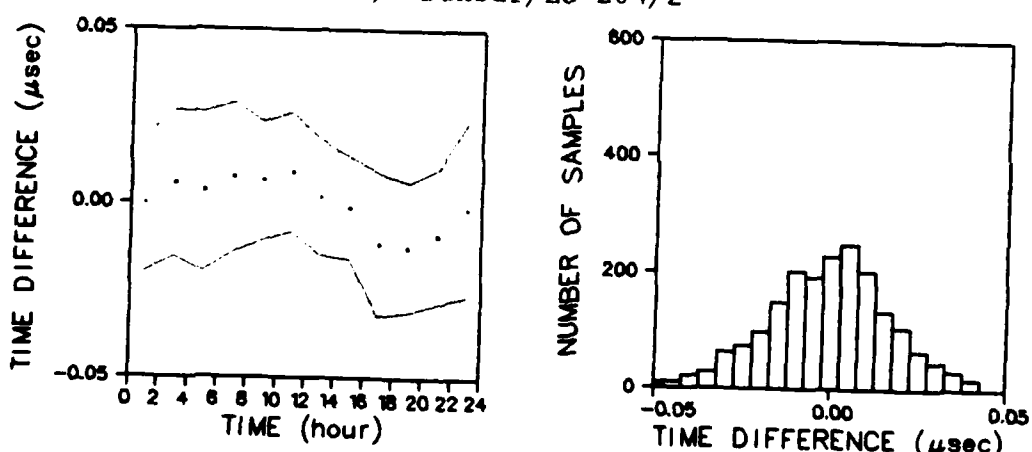
Figure 3.2-17 TDY Diurnal Cycles and Histograms for January



a) DeTour/LC-204/2



b) Dunbar/LC-204/2



c) Iroquois/LC-204/2

Figure 3.2-18 TDZ Diurnal Cycles and Histograms for January

- The diurnal cycle is obscured by random variations (i.e., a large standard deviation) for many time series, but is very distinct for others (e.g., see Fig. 3.2-14a)
- Some diurnal cycles exhibit a bimodal behavior, indicating a 12-hr period (e.g., see Fig. 3.2-17a)
- The 2-hr standard deviations are larger for January than for July, which is inconsistent with the lower atmospheric noise level known to occur in January (Ref. 10)
- The 2-hr standard deviations for July are generally larger at night (0 to 12 hours GMT) than during the day, which is inconsistent with the lower noise levels known to occur at night (Ref. 10)
- The random variations around the diurnal cycle can be characterized by a normal distribution with a standard deviation of approximately 0.02 μsec.

The high-frequency detail afforded by the 15-min sampling interval makes the St. Marys River Loran-C data base an important resource for future cause/effect analyses of diurnal variations.

3.3 CORRELATION AND SPECTRAL ANALYSES

3.3.1 Autocorrelation Functions and Power Spectral Densities

The relative contribution of seasonal, monthly, and diurnal TD variations is given by the Power Spectral Density (PSD), which is discussed in detail in Refs. 11 to 13. The following procedure is used to compute the PSD in the present study:

- Construct a smoothed time series, consisting of 2-hr averages of the original data, to reduce computer-processing requirements
- Synthesize TD data by linear interpolation to fill any time series gaps
- Remove the mean and trend (i.e., a straight-line fit) from the time series to minimize non-stationarity*
- Compute the Autocorrelation Function (ACF) of the time series by the technique described in Ref. 13, which involves the Fast Fourier Transform
- Multiply the ACF by a Kaiser window (Ref. 14), which has the effect of smoothing the PSD
- Compute the PSD as the Fast Fourier Transform of the ACF.

This procedure is adopted based on previous TASC experience in data processing, after conducting various tests on the present data.

The 2-hr averaging time is chosen because no significant spectral peaks are found to occur for periods† less than 10 hr. A 2-hr averaging time guarantees that the computed PSD is meaningful for periods greater than 4 hr, i.e., the Nyquist sampling period. Linear interpolation is selected for data synthesis, based on a comparison with two alternative techniques:

---

*Non-stationarity occurs when the length of the time series is short compared to the period of the low-frequency components (Ref. 12).

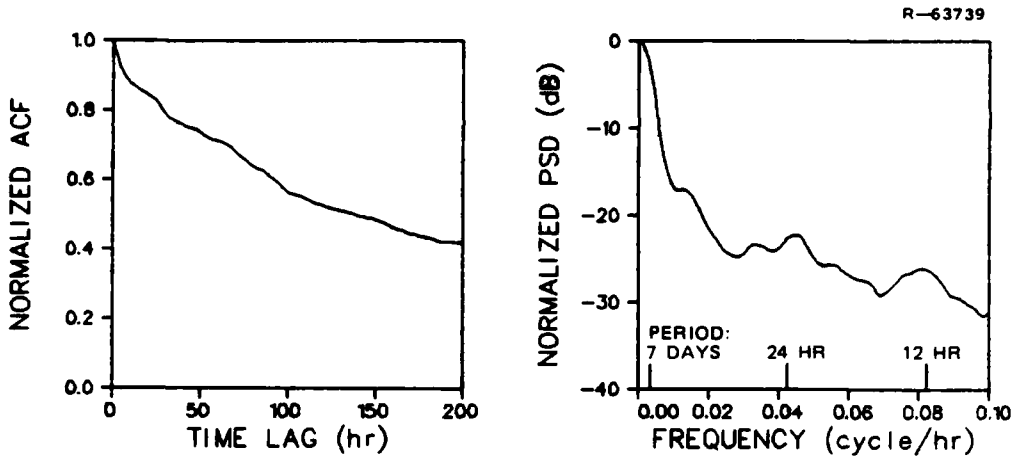
†The period of a spectral component is the inverse of the cyclical frequency.

placing zeroes in the gaps and ignoring the gaps (i.e., "squeezing" the time series). Interpolation preserves the low-frequency content of the data, and does not introduce discontinuities into the time series or associated spurious frequencies into the spectrum. Detrending is an important aspect of the PSD-computation procedure in cases where the TD values in May 1979 and May 1980 differ significantly. If the TD trend is not removed, the PSD and ACF are distorted by the occurrence of high energy near zero frequency.

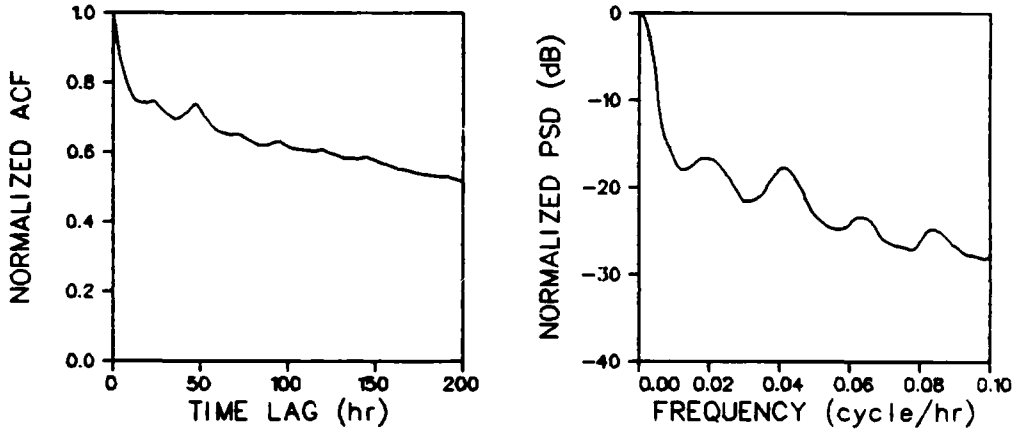
ACFs and PSDs computed by the aforementioned procedure are presented in Figs. 3.3-1 to 3.3-3. The time series all contain spectral peaks at the 24-hr and 12-hr periods (0.042 cycle/hr and 0.083 cycle/hr, respectively, in the PSD plots). The 24-hr diurnal peak is 10 to 20 dB below the zero-frequency spectral level and, in some cases, is more than 10 dB above the spectral level at adjacent frequencies (e.g., see Fig. 3.3-3b). The ACF generally decreases with increasing time lag, and contains a sinusoid-like component with a period of 24 hr.

The width of the 24-hr "hump" in the PSD depends on the seasonal variation (i.e., modulation) of the diurnal-cycle amplitude. The hump would be a "spike" if the diurnal cycle were a pure sinusoid with constant amplitude. The 12-hr component in the PSD may be partly due to the bimodal diurnal cycle identified in Section 3.2.3. However, such a component is expected to arise even for a unimodal diurnal cycle, if the cycle is not a pure amplitude-modulated sinusoid. Indeed, the 12-hr component is the first harmonic of the fundamental 24-hr component.

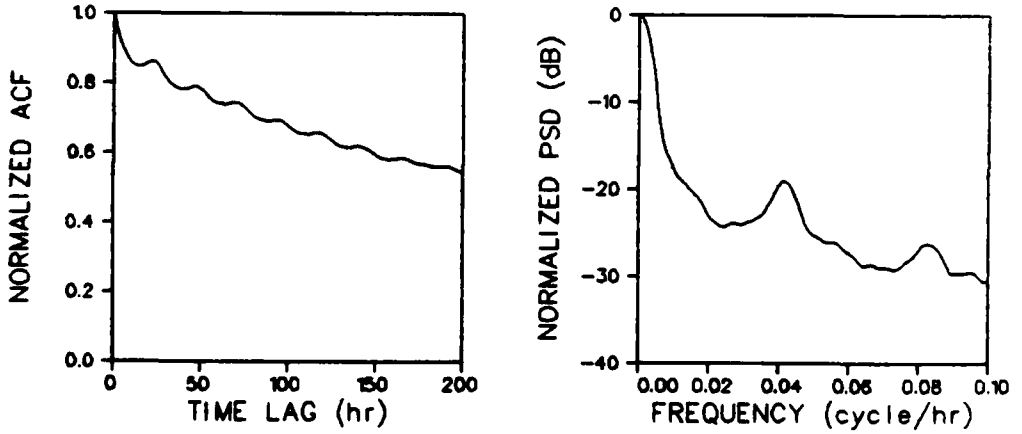
The slope of the ACF differs significantly for the various time series. The slope is governed largely by the



a) DeTour/LC-204/1

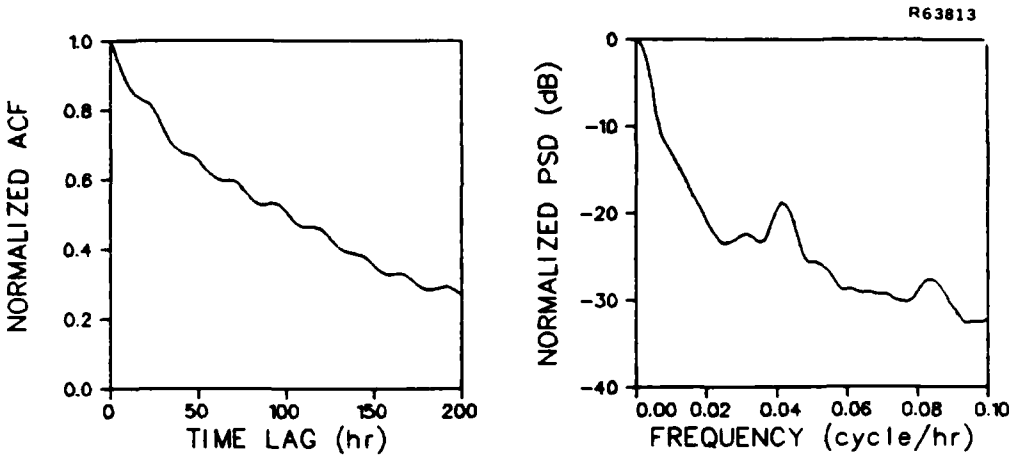


b) Dunbar/BRN-5/1

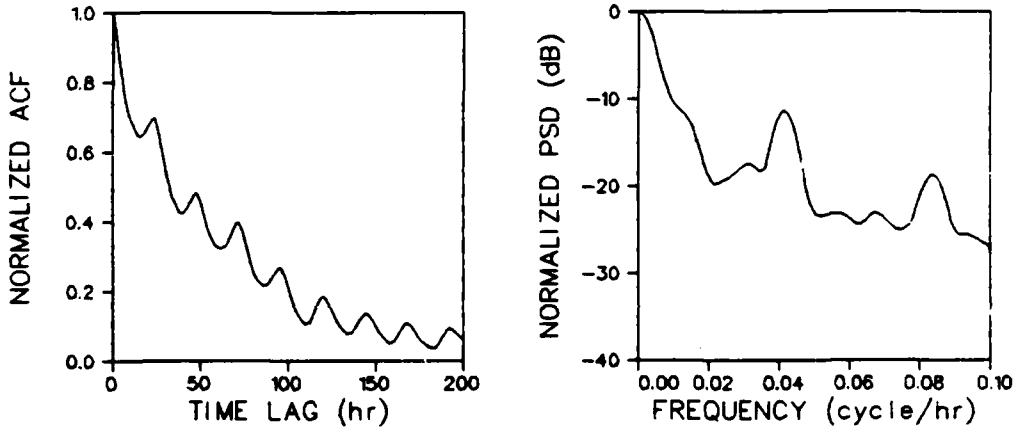


c) Iroquois/LC-204/1

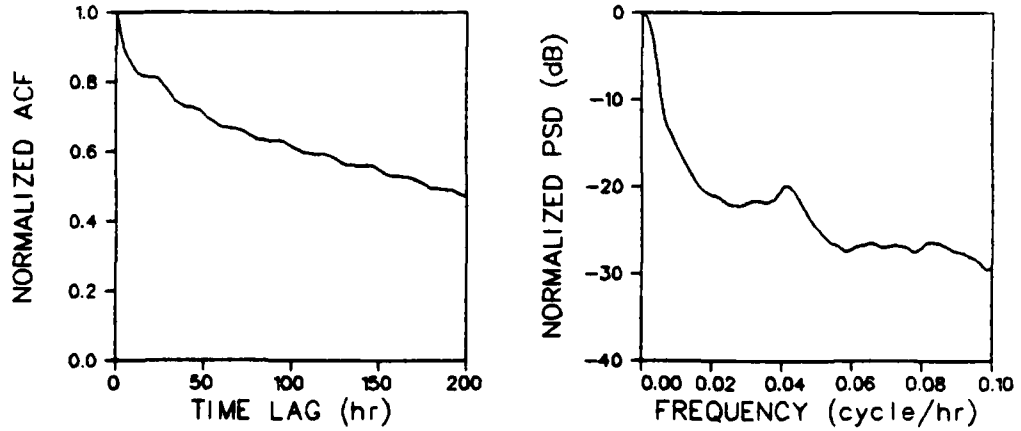
Figure 3.3-1 Autocorrelation Functions and Power Spectral Densities for TDX



a) DeTour/LC-204/2

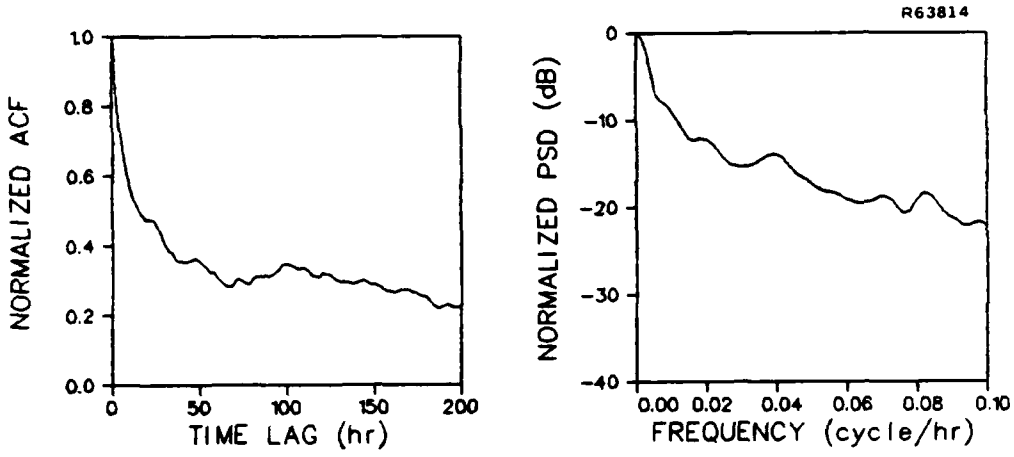


b) Dunbar/LC-204/2

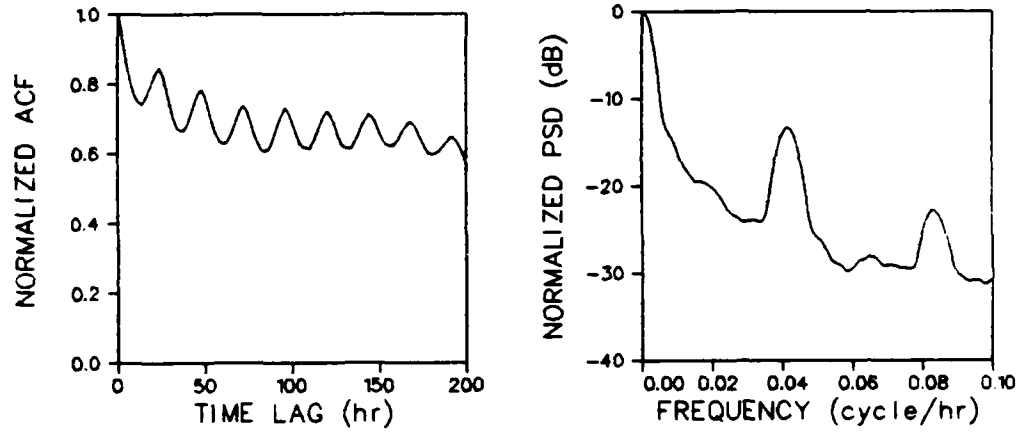


c) Iroquois/LC-204/2

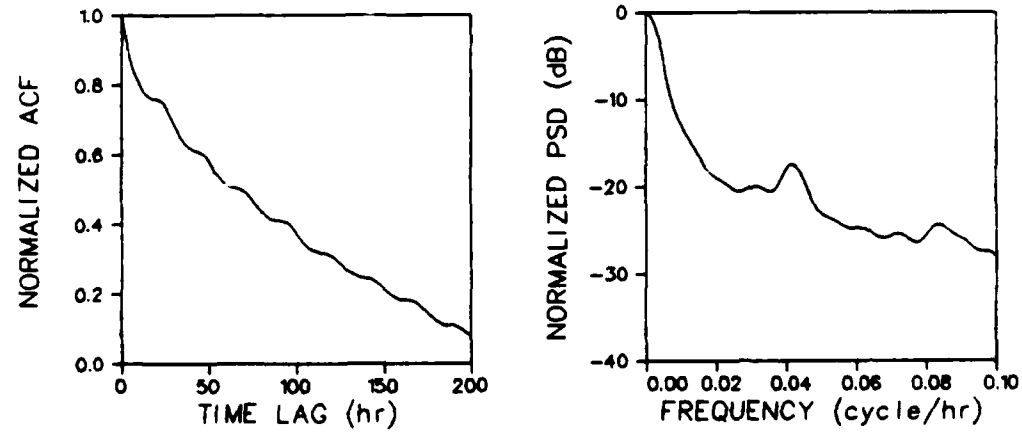
Figure 3.3-2 Autocorrelation Functions and Power Spectral Densities for TDY



a) DeTour/LC-204/2



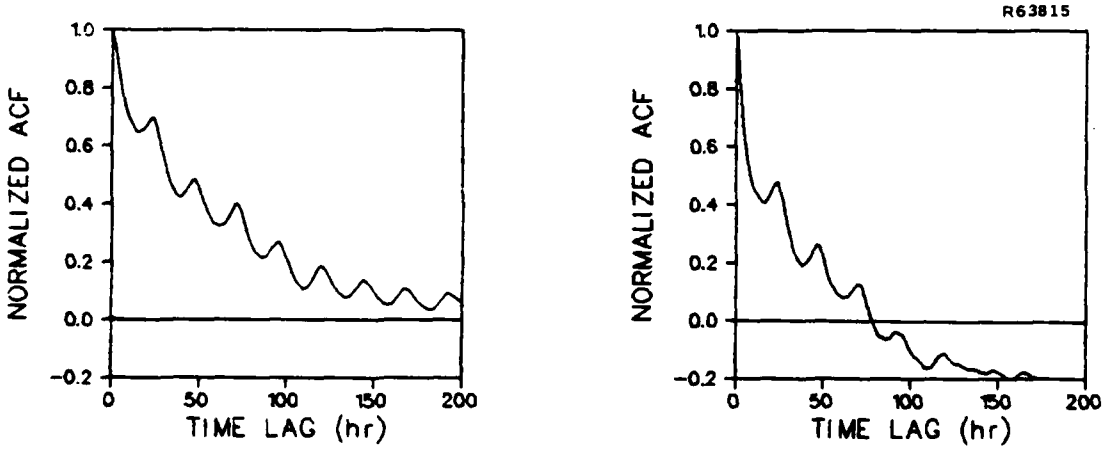
b) Dunbar/LC-204/2



c) Iroquois/LC-204/2

Figure 3.3-3 Autocorrelation Functions and Power Spectral Densities for TDZ

nature of the low-frequency (seasonal) variations. Because the seasonal variations may differ from year to year and the ACF is based on one year of data, the ACFs are not particularly useful for comparison purposes. In other words, the time series are not strictly stationary. Some improvement in stationarity can be achieved by high-pass filtering the data to remove seasonal variations which can not be removed by simple detrending. A comparison of ACFs, with and without filtering, is presented in Fig. 3.3-4 to illustrate this point. The ACF with filtering crosses zero at a time lag of approximately 3 days, which is consistent with U.S. Coast Guard analyses of one-month segments of low-density data (e.g., Ref. 16). Filtering is not performed in the ACF/PSD analyses in this study, to permit a comparison between the actual spectral levels at zero and diurnal frequencies. However, it should be kept in mind that the relative spectral levels may be different in other years.



a) No Filter (Same as Fig. 3.3-2b)

b) High-Pass Filter (Cut-Off Period = 30 days)

Figure 3.3-4 Effect of High-Pass Filtering on the ACF (TDY for Dunbar/LC-204/2)

3.3.2 Correlation of TD Pairs

Relationships among the various TDs are identified by correlating pairs of time series. The 3-day smoothed seasonal time series presented in Section 3.2.1 are used for this purpose.

Correlation coefficients (ρ) for TD pairs arranged by site are presented in Tables 3.3-1 to 3.3-3. Of particular interest is the correlation of redundant TDs, i.e., those measured at the same site with different receivers. Redundant TDY data collected with the two LC-204 receivers at DeTour exhibit a correlation coefficient of 0.94 and, therefore, are nearly identical. However, the redundant TDY data collected with the BRN-5 and LC-204 receivers at Dunbar are less highly correlated (ρ = 0.80). The smaller correlation may be caused by differences in the Magnavox and Internav signal-processing techniques or notch-filter settings. The low correlation between the TDZ data collected with the two LC-204 receivers at Iroquois (ρ = 0.61) suggests that at least one of these receivers may not be functioning properly.

Correlation coefficients for TD pairs arranged by station are presented in Tables 3.3-4 to 3.3-6. These results reveal that TDY data for the three sites are highly correlated (ρ = 0.87 to 0.94). This high correlation, together with the low correlation for TDX and TDZ, suggests that TDY variations are caused by a common non-propagation mechanism. The mechanism is necessarily associated with either the TDY channel of the Austron-5000 receiver at the SAM or with transmitter Y itself. The relationship between TDY and temperature variations is explored in Section 3.3.3.

TABLE 3.3-1
CORRELATION COEFFICIENTS FOR DETOUR

		LC-204/1		LC-204/2	
		TDX	TDY	TDY	TDZ
LC-204/1	TDX	+1.00	–	–	–
	TDY	+0.66	+1.00	–	–
LC-204/2	TDY	+0.36	+0.94	+1.00	–
	TDZ	+0.53	+0.07	+0.05	+1.00

TABLE 3.3-2
CORRELATION COEFFICIENTS FOR DUNBAR

		BRN-5/1		LC-204/2	
		TDX	TDY	TDY	TDZ
BRN-5/1	TDX	+1.00	–	–	–
	TDY	+0.89	+1.00	–	–
LC-204/2	TDY	+0.69	+0.80	+1.00	–
	TDZ	-0.69	-0.83	-0.08	+1.00

TABLE 3.3-3
CORRELATION COEFFICIENTS FOR IROQUOIS

		LC-204/1		LC-204/2	
		TDX	TDZ	TDY	TDZ
LC-204/1	TDX	+1.00	–	–	–
	TDZ	+0.41	+1.00	–	–
LC-204/2	TDY	+0.84	+0.40	+1.00	–
	TDZ	+0.59	+0.61	+0.71	+1.00

TABLE 3.3-4
CORRELATION COEFFICIENTS FOR TDX

		DETOUR	DUNBAR	IROQUOIS
		LC-204/1	BRN-5/1	LC-204/1
DETOUR	LC-204/1	+1.00	–	–
DUNBAR	BRN-5/1	+0.22	+1.00	–
IROQUOIS	LC-204/1	+0.18	+0.56	+1.00

TABLE 3.3-5
CORRELATION COEFFICIENTS FOR TDY

		DETOUR	DUNBAR	IROQUOIS
		LC-204/2	LC-204/2	LC-204/2
DETOUR	LC-204/2	+1.00	–	–
DUNBAR	LC-204/2	+0.94	+1.00	–
IROQUOIS	LC-204/2	+0.87	+0.88	+1.00

TABLE 3.3-6
CORRELATION COEFFICIENTS FOR TDZ

		DETOUR	DUNBAR	IROQUOIS
		LC-204/2	LC-204/2	LC-204/2
DETOUR	LC-204/2	+1.00	–	–
DUNBAR	LC-204/2	+0.10	+1.00	–
IROQUOIS	LC-204/2	+0.07	-0.17	+1.00

Each correlation coefficient presented above is a measure of the relationship between two seasonal time series. It is also of interest to determine the short-term correlation, by employing a more refined time scale. The coherency spectrum, which in effect shows the correlation coefficient as a function of frequency, is very useful in this regard. The coherency spectrum is related to the cross PSD, which in turn is computed as the Fast Fourier Transform of the cross-correlation function (Ref. 12). Examples of the cross-correlation function and coherency spectrum are given in Fig. 3.3-5 for TDX vs TDY data from the Dunbar/BRN-5/1 receiver. The coherency at zero frequency is approximately 0.89, the same as the correlation coefficient previously given in Table 3.3-2. However, the coherency decreases rapidly and is less than 0.50 for frequencies greater than 0.01 cycle/hr (i.e., periods less than 4 days). Based on these results, TD/TD relationships are expected to be more pronounced on a seasonal rather than diurnal time scale. The value of the cross-correlation function at zero time lag (0.75; see Fig. 3.3-5) can be interpreted as an "ensemble average" correlation coefficient over all frequencies. However, it should be recognized that this average value is weighted by the energy at each frequency and, thus, is closer to the zero-frequency coherency than otherwise expected.

3.3.3 Correlation of TDs with Temperature and Refractive Index

Meteorological data from the National Weather Service Station at Sault Sainte Marie, Michigan were provided to TASC on magnetic tape by the U.S. Coast Guard. The data include the dry-bulb, wet-bulb, and dew-point temperatures and the relative humidity, all recorded at 3-hr intervals. The 3-day

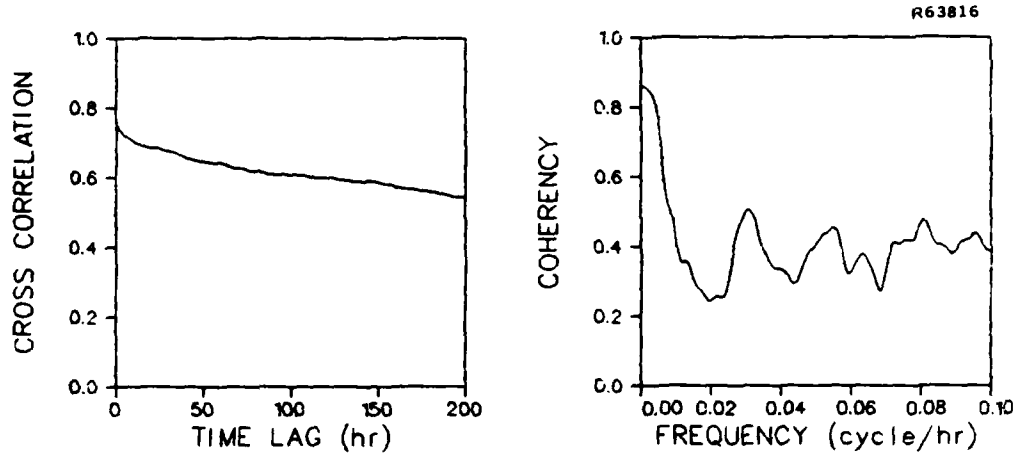


Figure 3.3-5 Cross-Correlation Function and Coherency Spectrum for TDX vs TDY Data (Dunbar/ BRN-5/1)

smoothed dry-bulb temperature is shown in Fig. 3.3-6 and refractivity*, computed by the formula in Refs. 3 and 8, is presented in Fig. 3.3-7.

Correlation coefficients for TDs vs temperature and TDs vs refractivity are given in Table 3.3-7. These results indicate a relatively strong negative correlation (ρ = -0.77 to -0.85) between TDY and temperature for all sites and receivers. Because the TD/temperature correlation is generally weaker for TDY than for TDX and TDZ, it appears that the temperature effect is not related to chain-wide propagation conditions. This contention is further justified by the TD/refractivity correlation coefficients presented in Table 3.3-7, which are all less than or equal to 0.61 in absolute value. The order of the TD/refractivity correlation coefficients is the same as for the TD/temperature correlation coefficients, because of the dependence of refractivity on temperature. However, the fundamental parameter is clearly temperature.

*Refractivity = (refractive index - 1.0) $\times 10^6$.

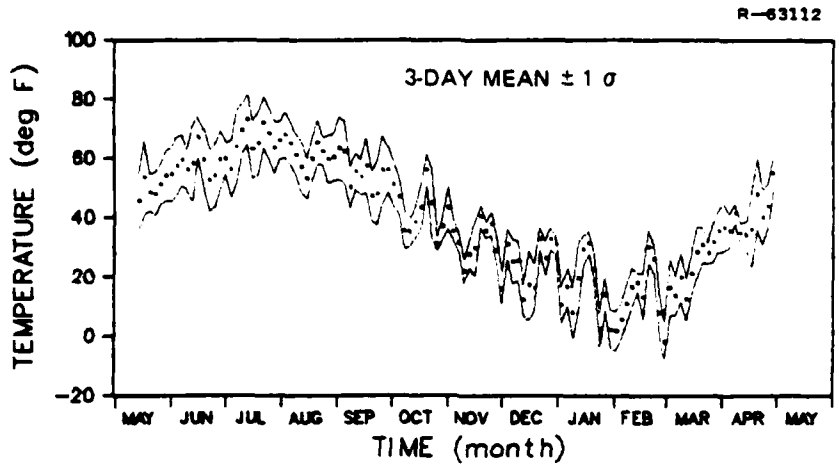


Figure 3.3-6 Temperature Seasonal Time Series

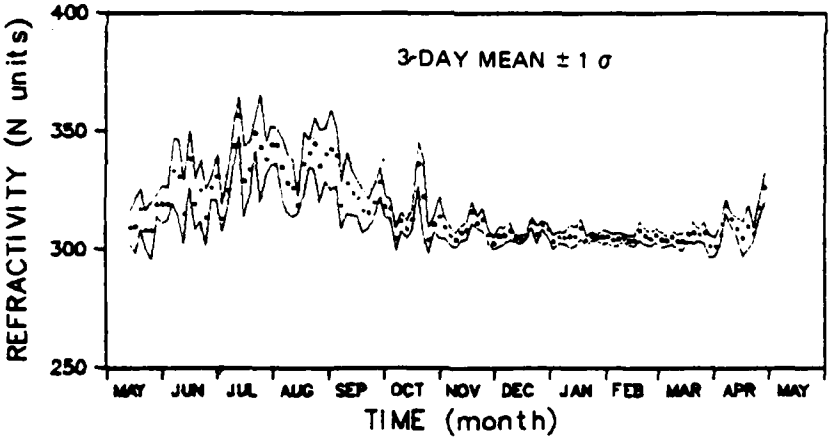


Figure 3.3-7 Refractivity Seasonal Time Series

TABLE 3.3-7

CORRELATION OF TDs WITH TEMPERATURE AND REFRACTIVITY

SITE	RECEIVER TYPE/ NUMBER	TIME DIFFERENCE	CORRELATION COEFFICIENTS	
			TD vs TEMPERATURE	TD vs REFRACTIVITY
DeTour	LC-204/1	X	-0.22	-0.14
		Y	-0.77	-0.55
DeTour	LC-204/2	Y	-0.84	-0.57
		Z	-0.19	-0.24
Dunbar	BRN-5/1	X	-0.70	-0.50
		Y	-0.80	-0.61
Dunbar	LC-204/2	Y	-0.85	-0.61
		Z	+0.54	+0.35
Iroquois	LC-204/1	X	-0.76	-0.56
		Z	-0.51	-0.31
Iroquois	LC-204/2	Y	-0.80	-0.60
		Z	-0.66	-0.51

The correlation between TDY and temperature is further explored by computing the cross-correlation function and coherency spectrum in the case of the Iroquois/LC-204/2 data (see Fig. 3.3-8). The coherency is approximately 0.80 at zero frequency, consistent with the correlation coefficient presented in Table 3.3-7. However, the coherency falls off rapidly with increasing frequency, suggesting that the effect of temperature is primarily seasonal. The U.S. Coast Guard has computed TD/temperature correlation coefficients based on 14-day smoothing (Ref. 21). The results show larger TDZ/temperature correlation coefficients for the Dunbar and Iroquois sites than those computed based on 3-day smoothing in the present study. The discrepancy is consistent with the coherency spectrum.

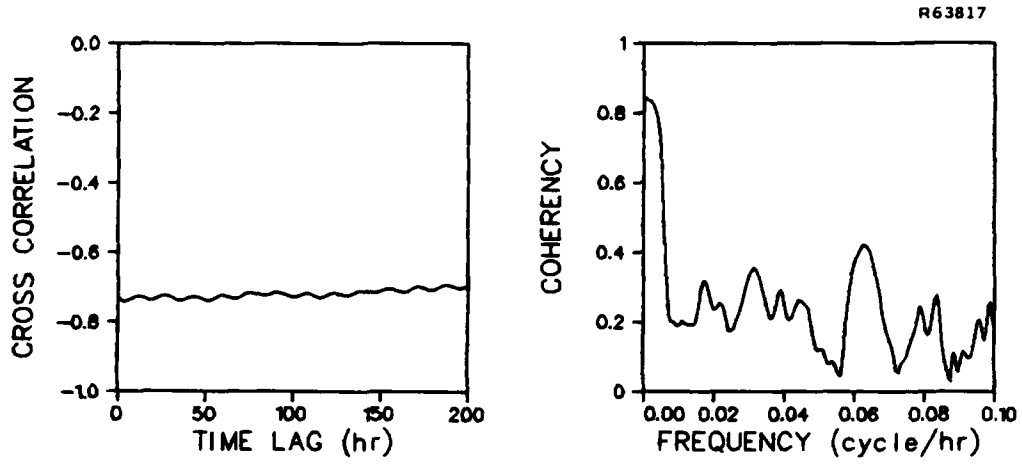
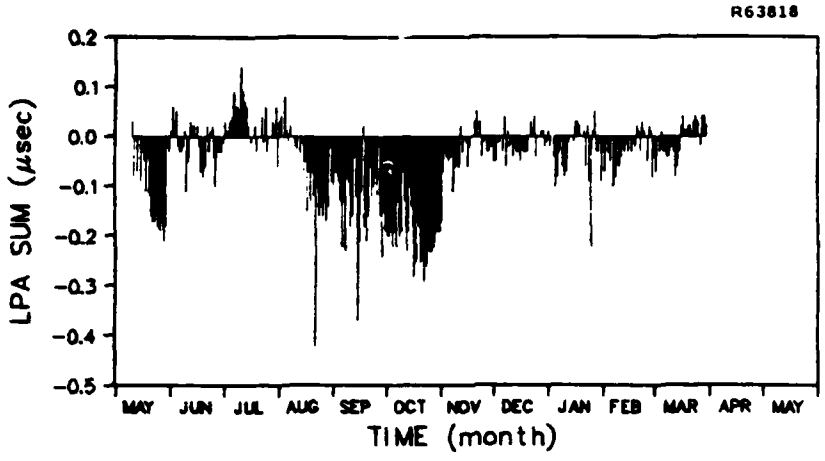


Figure 3.3-8 Cross-Correlation Function and Coherency Spectrum for TDY (Iroquois/LC-204/2) vs Temperature Data

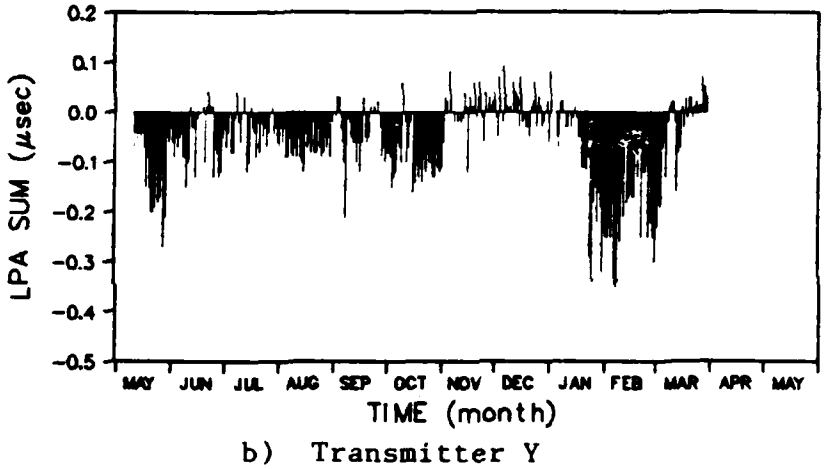
3.4 LPA STATISTICS

The LPA data contain information regarding the propagation variations which occur along transmitter-to-SAM signal paths. However, extraction of the information requires careful removal of clock phase drift caused by differences in the frequencies of the secondary and master cesium standards.

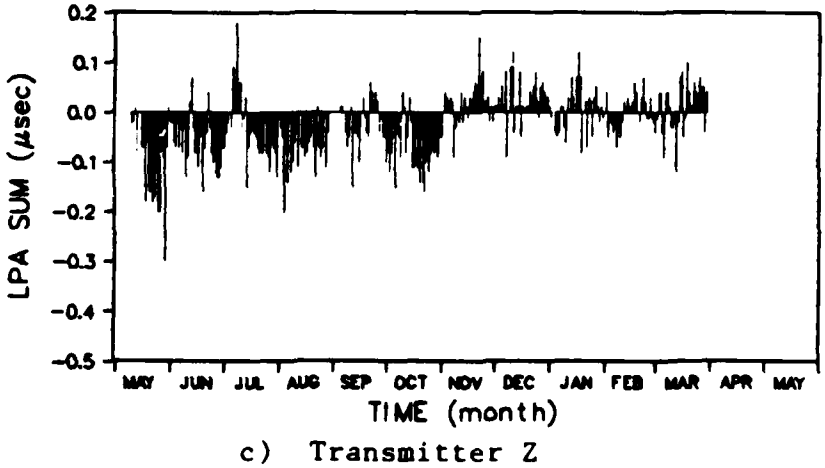
To illustrate this point, the daily sum of the LPAs is presented in Fig. 3.4-1 for each secondary transmitter. Inspection of the results for transmitter X might lead to the conclusion that propagation variations are larger in September than in January. However, a graph of the cumulative LPA sum vs time (see Fig. 3.4-2) shows that the large difference in



a) Transmitter X



b) Transmitter Y



c) Transmitter Z

Figure 3.4-1 Daily Sum of LPAs

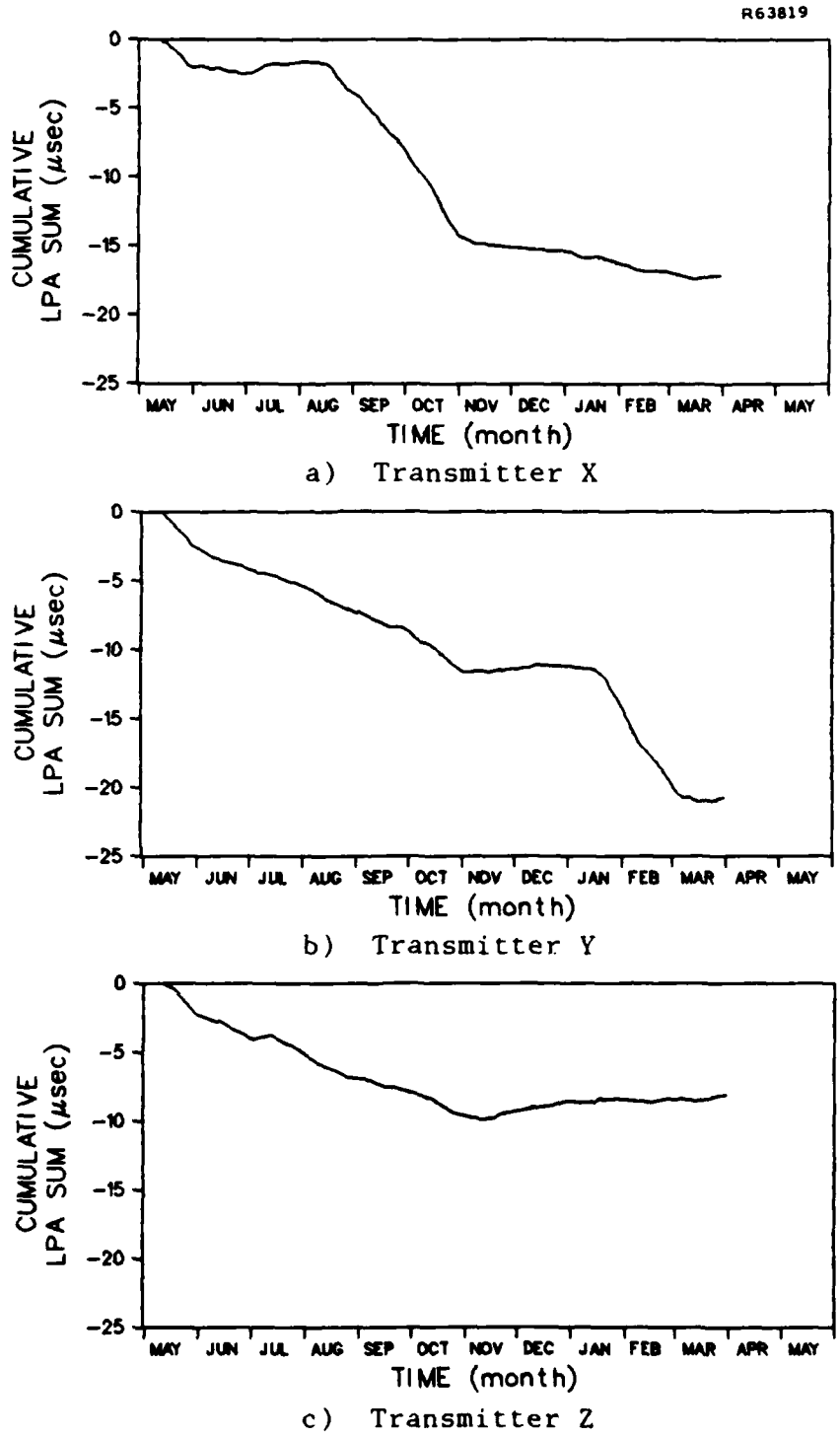


Figure 3.4-2 Cumulative Sum of LPAs

daily LPA sums is caused by a difference in clock drift rates for the two months. The drift rate in September is approximately 0.17 μsec/day, but after clock adjustments made in November the drift rate is only -0.02 μsec/day. Therefore, the daily LPA sums for September shown in Fig. 3.4-1a are primarily associated with clock synchronization, rather than propagation. Separation of synchronization and propagation effects is beyond the scope of the current effort.

3.5 COMPARISON OF THEORETICAL AND OBSERVED TD VARIATIONS

Signal propagation theory is employed in Ref. 3 to estimate the magnitude of St. Marys River Loran-C TD grid instability. Because the mini-chain coverage area is less than 60 nm in diameter, the propagation medium is assumed to be homogeneous. This simplifying assumption is consistent with the goal of estimating temporal TD variations, although it is not necessarily appropriate for a model of spatial variations (Refs. 1 and 2).

The sensitivity of TDs to temporal variations in three propagation parameters -- atmospheric refractive index, vertical lapse rate of refractive index, and ground conductivity -- is analyzed in Ref. 3. It is shown that TD sensitivity to refractive index and vertical lapse rate variations is proportional to the "Double Range Difference"

$$DRD = (R_s - R_m) - (R_s' - R_m') \qquad (3.5\text{-}1)$$

where R_s and R_m are the secondary-to-site master-to-site ranges, respectively, and R_s' and R_m' are the corresponding ranges to

the SAM. DRD contours are hyperbolas, as shown in Figs. 3.5-1 to 3.5-3. The contour of zero sensitivity (DRD = 0) passes through the SAM location, because the SAM maintains its TD at a constant level. TD sensitivity to conductivity variations is given by a Modified Double Range Difference

$$\text{Modified DRD} = (R_s^a - R_m^a) - (R_s'^a - R_m'^a) \qquad (3.5\text{-}2)$$

where the exponent "a" approximately equals 0.5. This modification accounts for the nonlinearity in the secondary phase delay vs. range function for ranges less than 100 nm (Ref. 15).

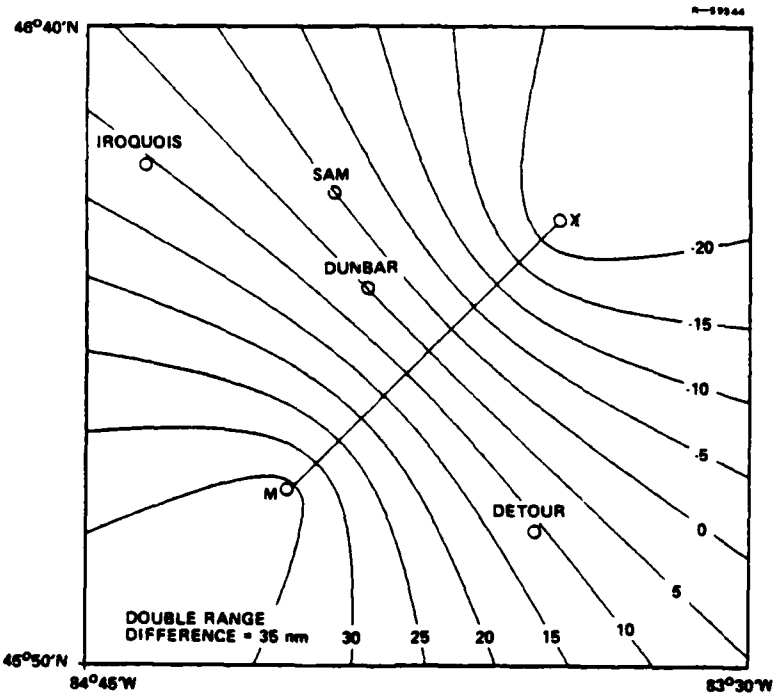


Figure 3.5-1 TDX Temporal Variation Sensitivity

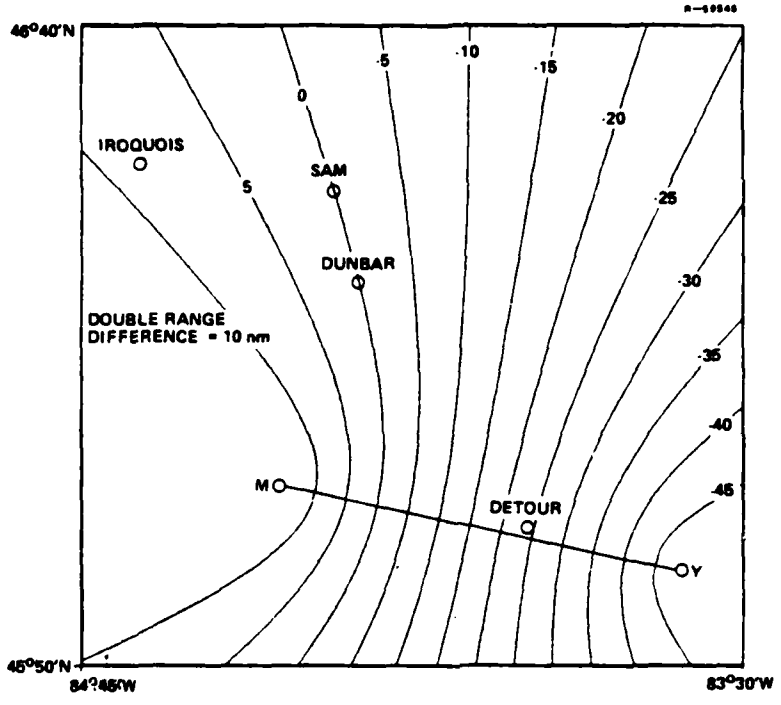


Figure 3.5-2 TDY Temporal Variation Sensitivity

The theoretical TD variations associated with particular variations in the propagation parameters are indicated below:

- Refractive Index -- 6×10^{-6} μsec/nm* per N-unit
- Vertical Lapse Rate -- 3×10^{-5} μsec/nm per 0.01 α-units
- Conductivity -- 4×10^{-3} μsec/nm per doubling of conductivity.

*TD variation per nm of DRD. For conductivity, a linear approximation is used to permit the DRD to replace the Modified DRD.

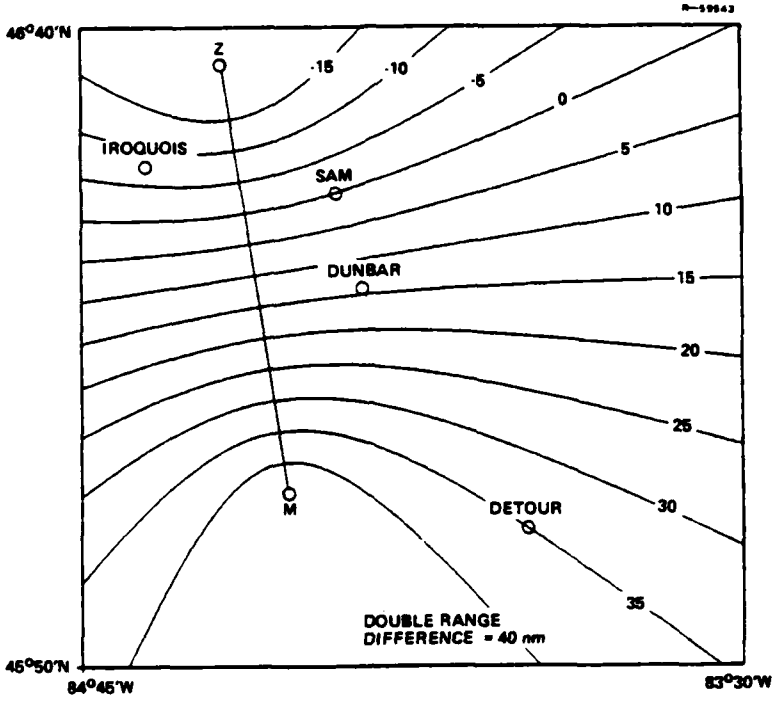


Figure 3.5-3 TDZ Temporal Variation Sensitivity

The maximum DRD for the St. Marys River Loran-C data collection sites is 35 nm (see Figs. 3.5-1 to 3.5-3). Therefore, the maximum seasonal TD variation expected for a 50 N-unit refractive index variation (see Fig. 3.3-7) is only 0.010 μsec. Similarly, the maximum seasonal TD variation expected for a 0.25 α-unit vertical lapse rate variation (Refs. 3 and 9) is 0.026 μsec. Clearly, the ±0.2-μsec seasonal TD variations shown in Section 3.2.1, if propagation-related, are necessarily caused by conductivity variations. The maximum TD variation expected for a doubling of conductivity from winter to summer (Ref. 3) is 0.14 μsec for the three data collection sites.

Although the maximum magnitude of the observed TD variations is consistent with propagation theory, the relative variations of the individual time series are not consistent with the DRD. This is illustrated in Fig. 3.5-4, a comparison of the seasonal time series and the corresponding DRDs. The following are among the obvious discrepancies:

- Dunbar TDY variations are 0.189 μsec peak-to-peak, but the DRD equals zero
- DeTour TDZ variations are only 0.061 μsec peak-to-peak, but the DRD equals +35 nm
- DeTour and Iroquois TDY variations are in the same direction, but the DRDs are of opposite sign (-25 nm vs +8 nm)
- DeTour and Iroquois TDX variations differ significantly, but the DRDs are both equal to +11 nm.

For the data collection sites considered, the Modified DRD is nearly proportional to the DRD and, therefore, does not contribute to resolving the discrepancies.

It is possible that seasonal conductivity variations are spatially heterogeneous, thereby violating the assumptions inherent in the DRD model. However, it is more likely that the observed TD variations are caused by a transmitter- and/or receiver-related mechanism, which dominates or disguises the propagation mechanism.

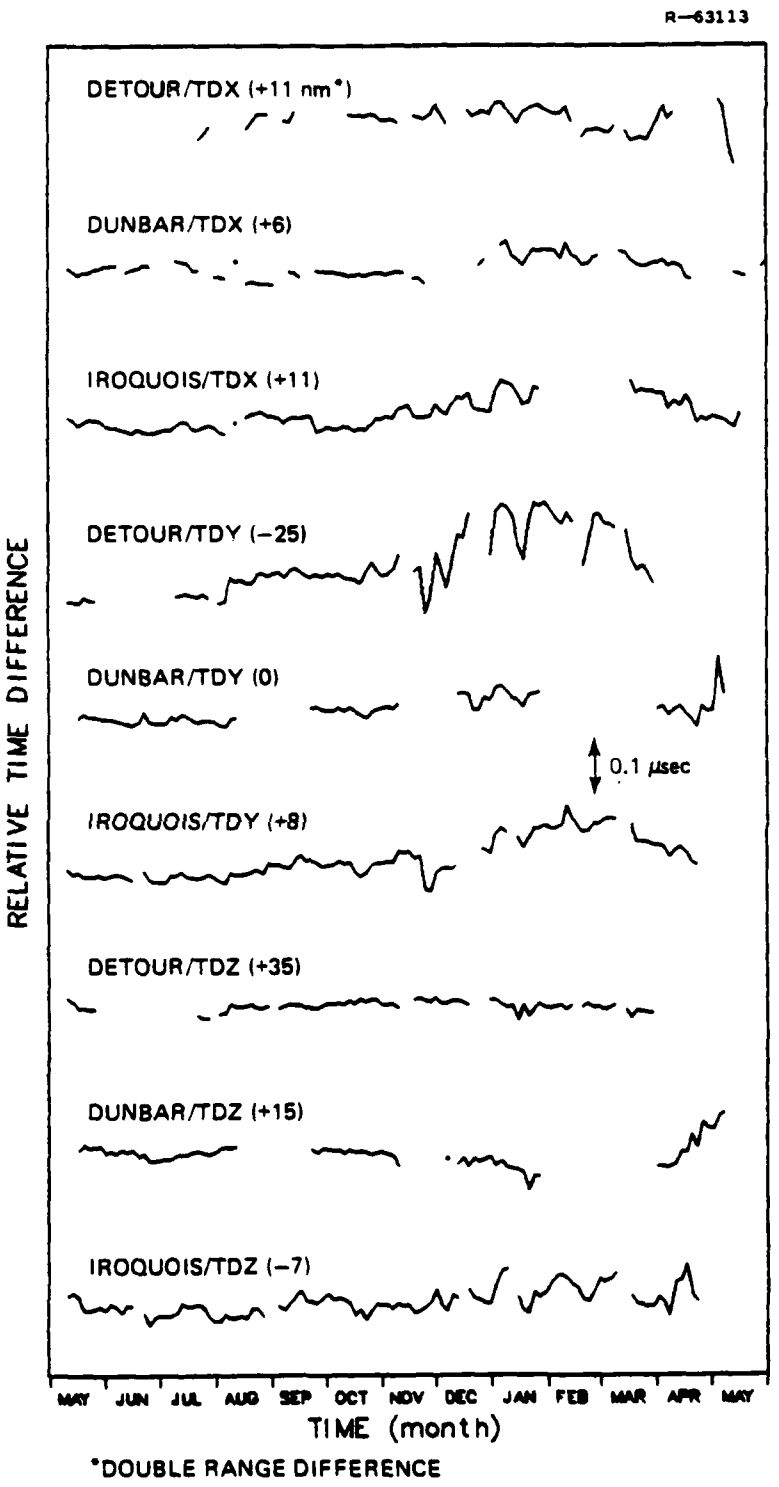


Figure 3.5-4 Comparison of Seasonal TD Time Series

4. EVALUATION OF LOW-DENSITY DATA ANALYSIS APPROACH

4.1 INTRODUCTION

The U.S. Coast Guard has conducted low-density data analyses, which closely parallel the high-density analyses presented in this report. The low-density approach is motivated by the desire of the U.S. Coast Guard to have a quick-response, in-house analysis capability. Specifically, the reduced data volume has enabled monthly internal reports to be issued, which summarize the analysis results (e.g., Ref. 6). A statistical evaluation of the low-density approach is presented in this chapter to validate the monthly reports and to establish an efficient Loran-C monitoring strategy for harbors.

4.2 COMPARISON OF EDITED LOW-DENSITY AND HIGH-DENSITY DATA

Potential errors in the low-density TD data, compared to the high-density data, can be categorized as follows:

- Relatively small errors associated with computing mean TD values based on a reduced sample size
- Relatively large errors resulting from the inability to detect outliers in short segments of a time series.

The first error category is addressed in this section, by employing low-density data extracted from the edited high-density data base. Such low-density data would result if

there were no outliers in the measured time series. The contribution of outliers is explored in Section 4.3.

"Generic" low-density sampling strategies are employed to investigate the effect of sample size. Each generic strategy is defined by three parameters:

- Number of equally-spaced time windows per day, during which 15-min samples are recorded
- Width of time windows
- Phase of time windows, i.e., the time-of-day at the beginning of the first window.

The nominal U.S. Coast Guard sampling strategy involves two time windows of width equal to 1 hr, beginning at 0 hr and 7 hr GMT. Because the windows are not equally-spaced (i.e., 12 hr apart), this strategy is addressed separately from the generic strategies.

4.2.1 Seasonal Variations

The utility of the low-density data in quantifying seasonal TD variations depends on the difference between the low- and high-density 3-day smoothed time series. The rms differences (i.e, errors) for the generic sampling strategies are presented as a function of window width in Fig. 4.2-1a and as a function of window phase in Fig. 4.2-1b. These results are obtained by processing TDY data from the Iroquois/LC-204/2 receiver, which is selected to represent worst-case seasonal variations. A direct comparison of the high-density and U.S. Coast Guard low-density time series is given in Fig. 4.2-1c.

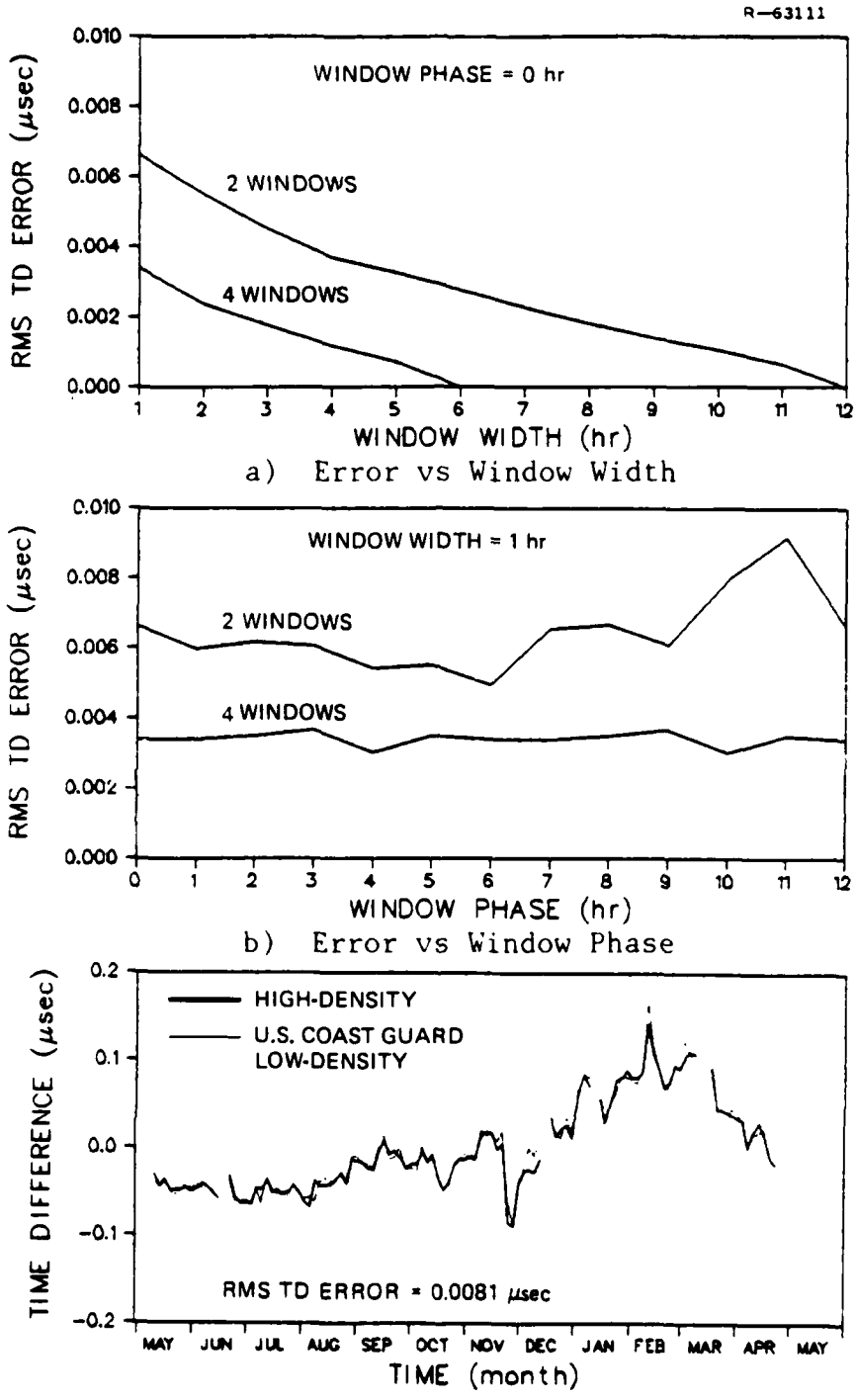


Figure 4.2-1 Accuracy of Edited Low-Density Seasonal Time Series (TDY for Iroquois/LC-204/2)

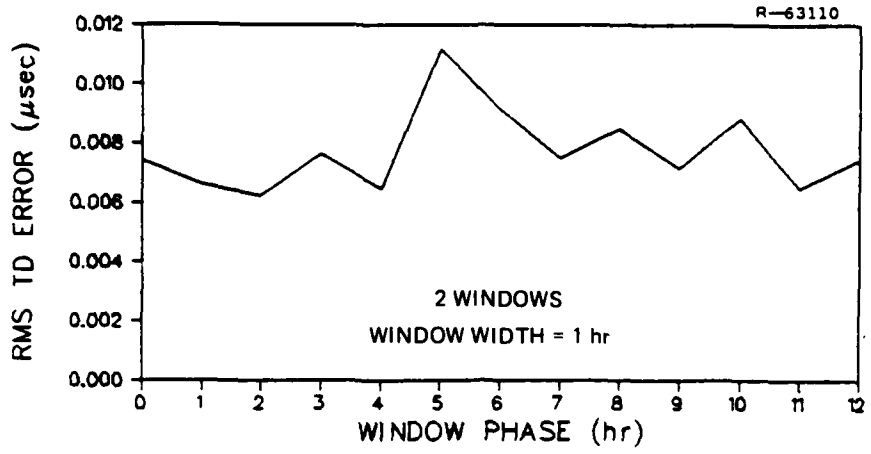
The following conclusions can be drawn, regarding the accuracy of the low-density seasonal time series:

- TD errors are less than 0.01 μsec rms for all strategies considered
- Four 1-hr windows are more effective than two 2-hr windows, although they contain the same number of samples
- TD errors are more sensitive to window phase for two windows than for four windows
- The U.S. Coast Guard sampling strategy could be improved only slightly (0.0081 μsec error to 0.0067 μsec error) by placing the windows at 0 hr and 12 hr GMT.

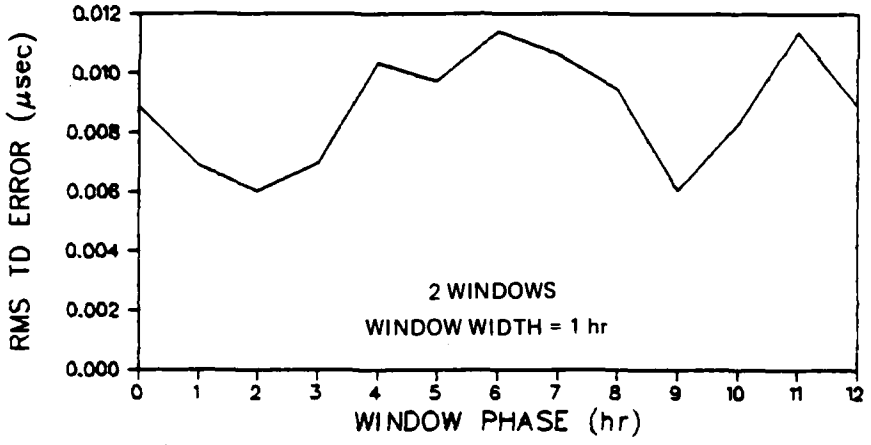
If TD errors are less than 0.01 μsec rms, as is the case for the U.S. Coast Guard sampling strategy, seasonal variations can be adequately identified. Although a significant reduction in TD errors can be achieved by using four 1-hr windows instead of two, the additional detail does not contribute significantly to the quantification of seasonal variations.

4.2.2 Monthly Variations

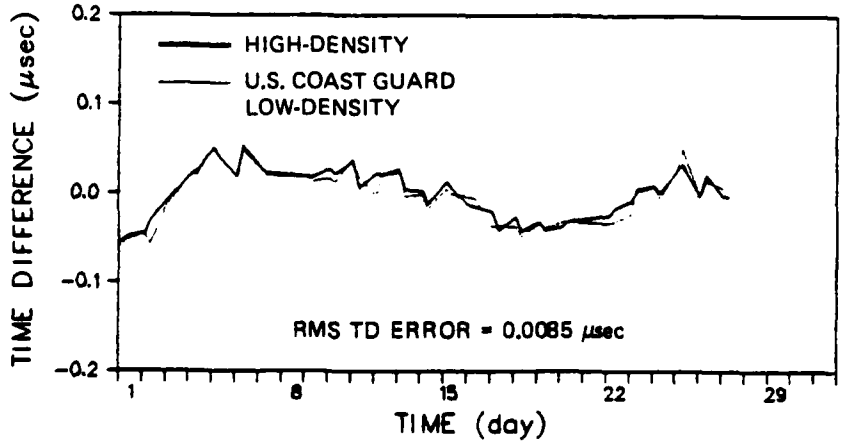
The utility of the low-density data in quantifying monthly TD variations depends on the difference between the low- and high-density 6-hr smoothed time series. The rms TD errors for the generic sampling strategies are presented as a function of window phase for July and January, in Figs. 4.2-2a and 4.2-2b, respectively. These graphs are based on TDX data from the Iroquois/LC-204/1 receiver, which exhibits worst-case TD variations for January. A comparison of the high-density and U.S. Coast Guard low-density time series for January is presented in Fig. 4.2-2c.



a) Error vs Window Phase for July



b) Error vs Window Phase for January



c) Comparison of Time Series for January

Figure 4.2-2 Accuracy of Edited Low-Density Monthly Time Series (TDX for Iroquois/LC-204/1)

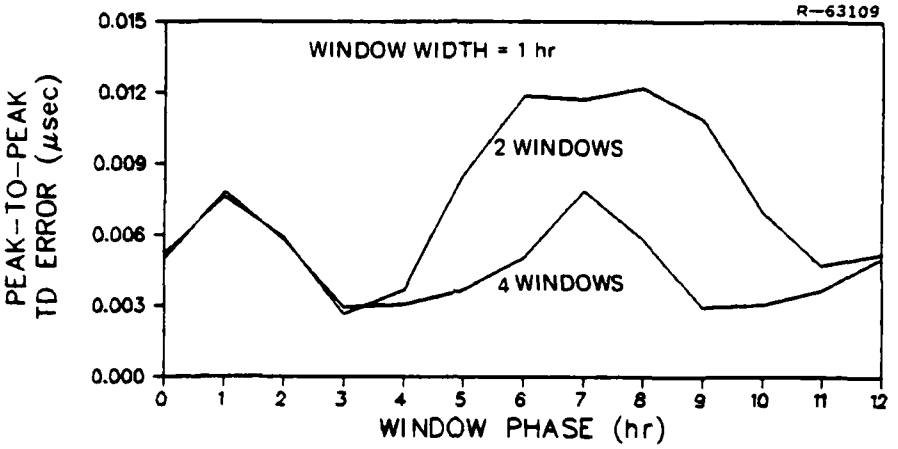
The low-density monthly time series is somewhat less accurate than the low-density seasonal time series but, nevertheless, is in error by less than 0.012 μsec rms. Consequently, the U.S. Coast Guard sampling strategy is judged to be adequate for measuring monthly TD variations. The large sensitivity of TD errors to window phase, especially for the January data (see Fig. 4.2-2b), is apparently not related to the diurnal TD cycle. Indeed, the TDX diurnal cycle for January for the Iroquois/LC-204/1 receiver is less than 0.005 μsec peak-to-peak (see Fig. 3.2-16c). Rather, the two minima in the TD-error vs window-phase graph arise from the assumed definition of a monthly time series. Specifically, the best estimate of the 6-hr means is obtained by sampling in the center of the 6-hr intervals, i.e., at 3 hr, 9 hr, 15 hr, and 21 hr GMT.

4.2.3 Diurnal Variations

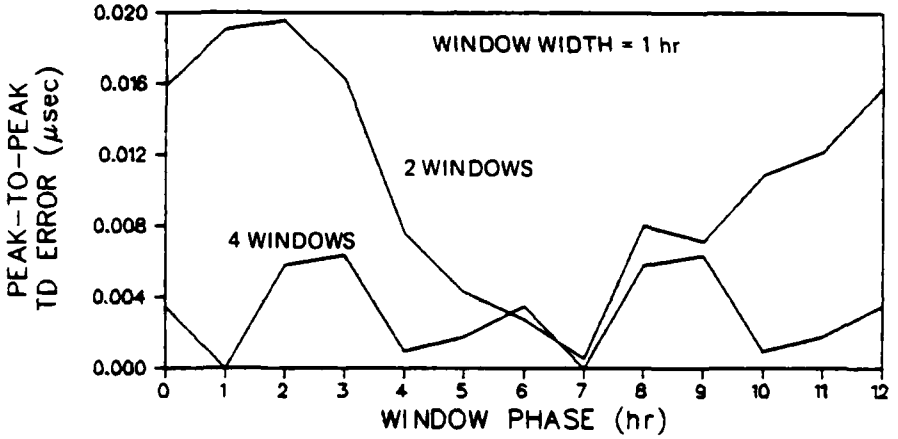
Intuitively, it is difficult to accurately measure the peak-to-peak value of the diurnal TD cycle by using only two 1-hr windows. The phase of the windows is a critical parameter in this case, more so than in the measurement of seasonal and monthly TD variations.

The error in the peak-to-peak value of the low-density diurnal cycle* is presented as a function of window phase for July and January, in Figs. 4.2-3a and 4.2-3b, respectively. TDZ data from the Iroquois/LC-204/2 receiver are selected for the analyses, because they exhibit a distinct diurnal cycle. The high-density and U.S. Coast Guard low-density diurnal cycles are compared for July and January, in Figs. 4.2-3c and 4.2-3d, respectively.

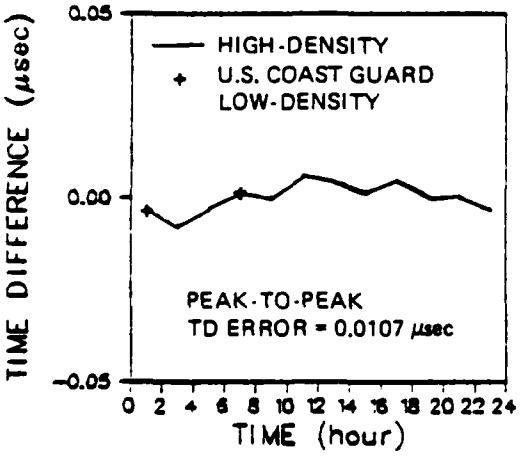
*For two 1-hr windows, the "diurnal cycle" consists of two points, each computed as described in Section 3.2.3.



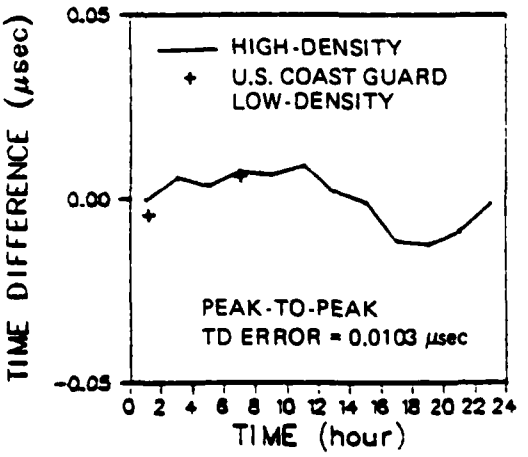
a) Error vs Window Phase for July



b) Error vs Window Phase for January



c) July Comparison



d) January Comparison

Figure 4.2-3 Accuracy of Edited Low-Density Diurnal Cycle (TDZ for Iroquois/LC-204/2)

The following conclusions are drawn regarding the accuracy of the low-density diurnal cycle:

- TD cycle errors are more sensitive to window phase in January than in July, because the diurnal cycle amplitude is larger in January
- The optimal window phase is different in July than in January, because the phase of the diurnal cycle is different in the two months
- TD cycle errors for January, range from less than 0.001 μsec to 0.020 μsec, depending on the choice of window phase
- Sensitivity to window phase is greatly reduced by using four windows instead of two
- The "peak" in the July diurnal cycle and the "trough" in the January diurnal cycle are not observable with the U.S. Coast Guard sampling strategy, thereby resulting in a 50-percent error in the measured cycle amplitudes.

It is important to recognize that the optimal window phase is generally different for the other TD time series (see Figs. 3.2-13 to 3.2-18).

Clearly, the U.S. Coast Guard low-density data should not be employed for diurnal analyses. Use of the data to identify spectral components for periods less than or equal to 24 hr leads to an aliasing error (Ref. 13). To minimize this problem, it is recommended that four or more time windows per day be employed in the Loran-C harbor monitor program.

4.3 EFFECT OF OUTLIERS ON LOW-DENSITY DATA

The high-density editing procedure described in Chapter 2 consists of three steps: signal-quality check (Editing Mark 2), tolerance check (Editing Mark 3), and outlier editing (Editing Mark 6). A signal-quality check is performed in the microprocessors of the low-density data-recording system, and a tolerance check is performed by the U.S. Coast Guard upon receipt of the data. However, the ability to detect outliers is limited by the short (1-hr) contiguous time periods during which 15-min samples are available. In particular, there are not enough samples to compute a reliable daily trend line (see Section 2.2.6).

Outliers occur in a small percentage of the 1-hr windows: only 1.9 to 10.8 percent of the high density-data are outliers, and only one-twelfth (8.3 percent) of the high-density data are involved in the low-density analyses. Therefore, a comparison of time series, analogous to the comparisons presented in Section 4.2, is not particularly useful for showing the effect of outliers. The following alternative approach is selected and applied to the TDY time series for the DeTour/LC-204/1 receiver:

- Partition the time series into 1-hr intervals and consider only those intervals which contain outliers
- Calculate the differences (errors) between the 1-hr TD means computed with and without outliers
- Construct a histogram of the TD errors.

The histogram shows the distribution of all potential errors encountered in a low-density monthly time series*, due to the presence of outliers. However, very few of the errors are actually encountered, because very few 1-hr intervals with outliers are involved in the low-density data.

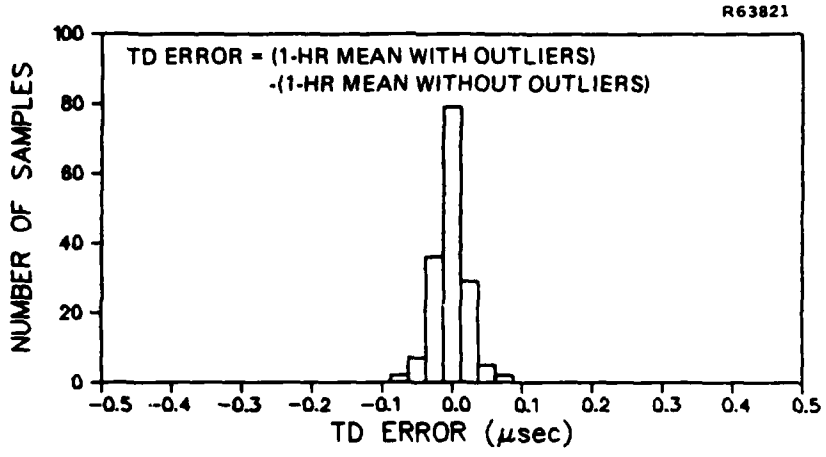
Histograms are presented in Fig. 4.3-1 for three definitions of outliers: Editing Mark 6 = "1", "1" to "4", or "1" to "6". It is unlikely that outliers with Editing Mark 6 = "1" can be detected in the low-density data. However, the potential TD errors introduced by these outliers are typically less than 0.04 μsec, not a major concern. Outliers with Editing Mark 6 = "2" to "4" can be detected by a careful inspection of the low-density data, except when multiple outliers occur in a 1-hr window. Such an inspection is warranted because the TD errors can be as large as 0.10 μsec. As indicated in Fig. 4.3-1c, outliers with Editing Mark 6 = "5" or "6" can cause TD errors as large as 0.2 μsec. Fortunately, these gross outliers are easily detected and removed from the low-density data. The implication of the skewed histogram in Fig. 4.3-1c is that gross outliers consistently lie below the daily trend line, suggesting a possible anomaly in the DeTour/ LC-204/1 receiver.

4.4 ASSESSMENT OF LOW-DENSITY DATA ANALYSIS TECHNIQUES

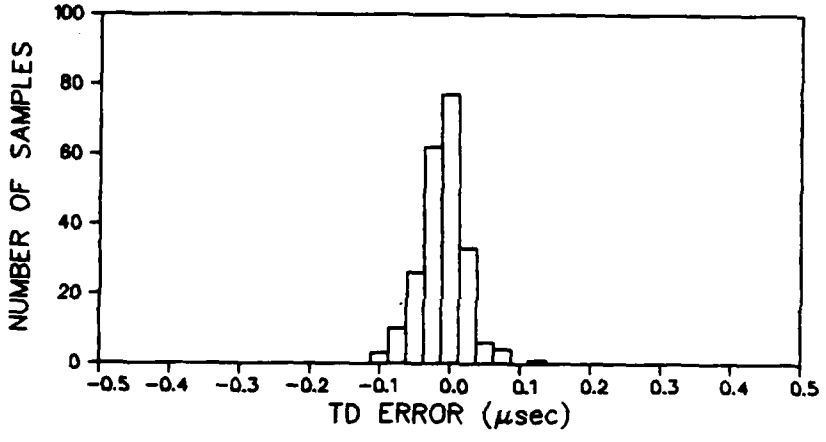
The following are among the low-density data analysis techniques used by the U.S. Coast Guard (Refs. 17 and 18):

- K-Factor Analysis -- used to predict relative TD variations in an assumed homogeneous chain coverage area

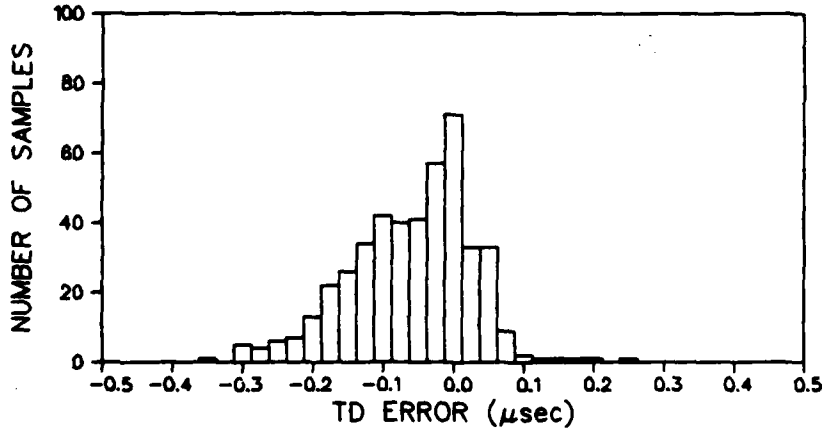
*The low-density monthly time series necessarily consists of 1-hr means, rather than 6-hr means.



a) Editing Mark 6 = "1"



b) Editing Mark 6 = "1" to "4"



c) Editing Mark 6 = "1" to "6"

Figure 4.3-1 Effect of Outliers on Low-Density Monthly Time Series (TDY for DeTour/LC-204/1)

- Uniform Propagation Velocity Model -- used to extract propagation velocity and common SAM-induced errors from the TD data
- Radial Position Error Estimation --used to project propagation velocity variations, SAM-induced errors, and measurement noise into Loran-C user position errors
- TD/Temperature Correlation Analysis -- used to confirm the TD/vertical lapse rate relationship expected by the U.S. Coast Guard.

TASC believes these analysis techniques are appropriately and correctly applied, except as noted below.

K-factor analysis is equivalent to the Double Range Difference analysis presented in Section 3.5. The technique is based on the assumption that the propagation delay increases linearly with range. If conductivity variations are more important than vertical lapse rate variations, however, the dependence is nonlinear in range. In this case, a modified K-factor, analogous to the Modified Double Range Difference (see Eq. 3.5-2), is a more accurate index.

A similar modification to the geometry matrix of the uniform propagation velocity model is required to accommodate conductivity variations. It is also cautioned that the "common SAM-induced error" appearing in the model includes a zero-range bias in the propagation velocity vs range function. This artificial bias occurs because the data cover a limited set of ranges and the assumed velocity vs range function is an approximation. The "bias" varies with time, in conjunction with the modeled propagation velocity variations.

It is shown in Ref. 1 that the cross-channel position error is significantly smaller than the radial (specifically, the 2d rms) position error, in certain areas of the St. Marys River navigation channel. Therefore, it is recommended that both the cross-channel and radial position errors, or the cross-channel and along-channel position errors, be included in comparisons with the channel width (Ref. 17).

TD/temperature correlation analyses, similar to those presented in Section 3.3.3, are an important part of the U.S. Coast Guard low-density approach. It is recommended that the analyses be limited to correlation coefficients. The cross-correlation function is very sensitive to the nature of low-frequency effects and, therefore, cannnot be relied on for comparison purposes. Although agreeing that TD/temperature relationships must be identified, TASC is not in agreement with the U.S. Coast Guard contention that such relationships are primarily a vertical lapse rate effect (Ref. 17). The theoretical results in Refs. 3 and 9 show clearly that the TD variations induced by vertical lapse rate variations are negligible (<0.03 μsec) in a short-baseline chain. It appears from the results presented in this report that the high TD/temperature correlation observed in the data is not related to propagation. To further test this hypothesis, it is recommended that vertical lapse rate data from the National Weather Service Station at Sault Sainte Marie, Michigan be correlated against the TD data. In computing the vertical lapse rate from radiosonde data, it should be kept in mind that the results may be sensitive to the altitudes selected for the computation (Ref. 20). Various altitudes in addition to the surface/1-km standards should be tested.

5. CONCLUSIONS AND RECOMMENDATIONS

Results of a detailed analysis of St. Marys River temporal Loran-C data, collected by the U.S. Coast Guard from May 1979 to May 1980, are documented in this report. The following objectives are met by the data analysis effort:

- Quantification of Time Difference (TD) grid instability in the St. Marys River Loran-C mini-chain, based on high-density (15-min) data
- Establishment of an efficient Loran-C monitoring strategy for harbors, based on an evaluation of the U.S. Coast Guard low-density* data analysis approach.

Data-organizing and -editing capabilities, needed to support the analyses, are provided by the TASC Loran-C Data-Base Management Software developed in a previous effort (Ref. 5). Conclusions and recommendations related to the two study objectives are presented below.

5.1 QUANTIFICATION OF ST. MARYS RIVER LORAN-C TD GRID INSTABILITY

The following principal conclusions are drawn from analyses of the high-density TD time series data:

*Low-density data consist of five 15-min samples recorded twice daily.

- Seasonal TD variations (i.e., variations in 3-day means over the data collection period) are less than 0.4 μsec peak-to-peak at the three data collection sites, consistent with previous observations (Refs. 2 and 3)

- TD variations during monthly periods are larger in the winter than in the summer (e.g., see Fig. 5.1-1), consistent with signal propagation theory (Refs. 3 and 9)

- Diurnal TD cycles are generally less than 0.02 μsec peak-to-peak, which is small relative to longer-term variations (e.g., see Fig. 5.1-2)

- Power Spectral Densities (PSDs) computed from the data show that the diurnal TD cycle is 10 to 20 dB below the zero-frequency spectral component (e.g., see Fig. 5.1-3)

- TDZ data measured at the Pt. Iroquois site differ significantly for the two Internav LC-204 receivers (the correlation coefficient, ρ, is 0.61)

- TDY data from the three sites are highly correlated (ρ = 0.87 to 0.94)

- TDY data exhibit a relatively high negative correlation with Sault Sainte Marie temperature data (ρ = -0.77 to -0.85).

A comparison of the data analysis results to the theoretical predictions given in Ref. 3 shows that the maximum observed TD variation is consistent with expected seasonal conductivity variations. However, the relative variations of the individual time series are not consistent with propagation theory for a homogeneous medium.

It is possible that seasonal conductivity variations are spatially heterogeneous, thereby violating the assumptions made in Ref. 3. However, it appears more likely that the observed TD variations are caused by a transmitter- and/or

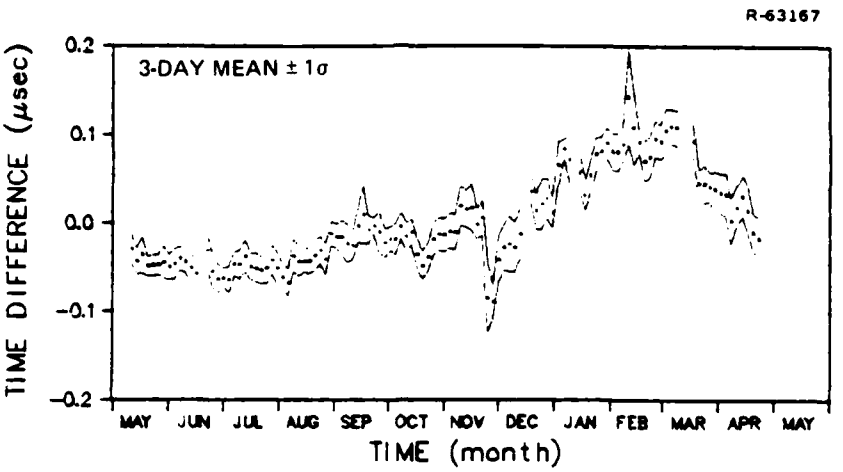


Figure 5.1-1 TDY Seasonal Time Series for Iroquois/LC-204/2

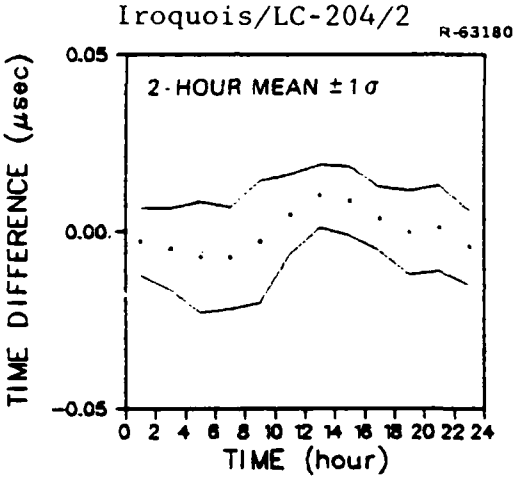


Figure 5.1-2 TDY Diurnal Cycle for DeTour/LC-204/2

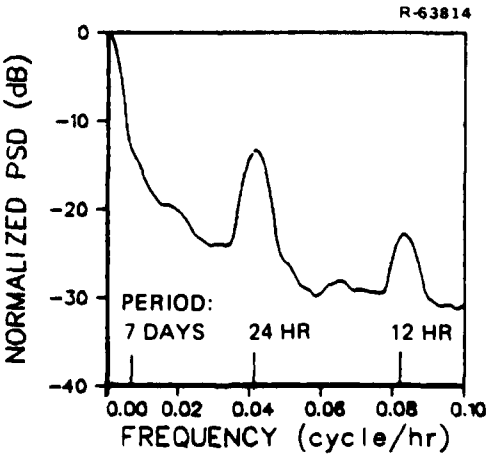


Figure 5.1-3 TDZ Power Spectral Density for Dunbar/LC-204/2

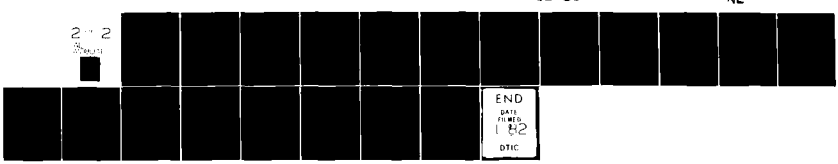
receiver-related mechanism, which disguises the propagation effect. It is important to establish the nature of this mechanism, because of its potential impact on the Loran-C harbor monitor program. Therefore, it is recommended that additional data analyses be conducted, to search for possible cause/effect relationships, whether they be propagation- or transmitter/receiver-induced (Ref. 19). The data base described herein is the most comprehensive of its kind ever assembled and provides a strong nucleus for such an effort.

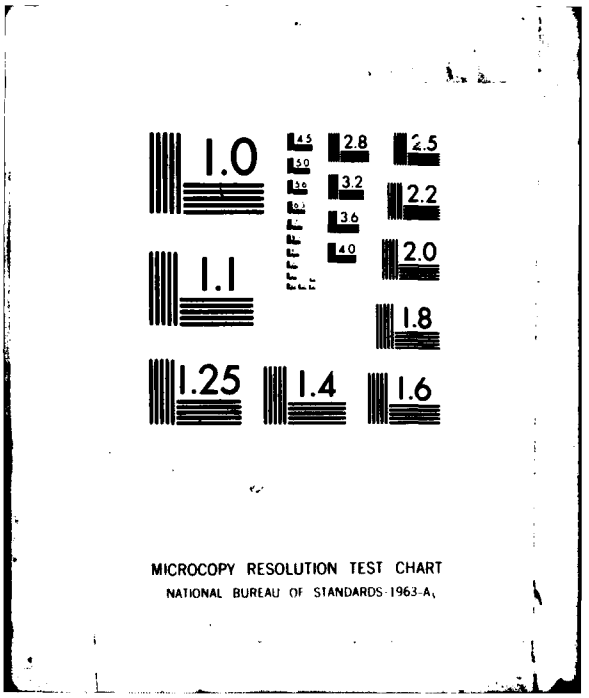
5.2 EVALUATION OF LOW-DENSITY DATA ANALYSIS APPROACH

The following principal conclusions are drawn from the evaluation of the U.S. Coast Guard low-density data analysis approach:

- Errors in the low-density seasonal TD time series, relative to the high-density time series, are less than 0.01 μsec rms
- A reduction in the low-density seasonal time series errors can be realized by increasing the number of samples collected per day, but the reduction results in only a slight improvement in data utility
- The above conclusions also hold for the low-density monthly time series
- Significant errors (as large as 50 percent) result if the low-density data are used to compute the peak-to-peak value of the diurnal TD cycle
- The low-density diurnal-cycle errors are very sensitive to the times-of-day selected for sampling
- The optimal sampling times for diurnal-cycle resolution generally differ for different months and different receiver/TD combinations

AD-A108 074 ANALYTIC SCIENCES CORP READING MA F/G 17/7
QUANTIFICATION OF ST. MARYS RIVER LORAN-C TIME DIFFERENCE GRID --ETC(U)
AUG 80 DOT-CG-A1-77-1785
UNCLASSIFIED USCG-D-52-81 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

- Moderate data outliers are not a problem in the low-density data, but gross outliers must be removed by inspection.

Based on these conclusions, it is recommended that the U.S. Coast Guard low-density data not be employed for diurnal analyses. To permit diurnal analyses in the Loran-C harbor monitor program, the number of 1-hr time windows per day should be increased from two, to at least four. Furthermore, it must be recognized that the analysis results herein pertain specifically to the St. Marys River mini-chain. In anticipation that different results may apply to a long-baseline chain, it is recommended that high-density harbor monitor data be collected during both a summer month and a winter month and analyzed prior to standardizing a low-density sampling strategy.

The U.S. Coast Guard low-density data analysis techniques described in Ref. 17 are judged to be appropriately and correctly applied, with a few minor exceptions (see Section 4.4). However, TASC is not in agreement with the U.S. Coast Guard contention that the high TD/temperature correlation observed in the data is primarily a vertical lapse rate effect. Based on signal propagation theory, the vertical lapse rate effect is expected to be negligible in a mini-chain. To resolve this issue, it is recommended that vertical lapse rate data from the National Weather Service Station at Sault Sainte Marie, Michigan be correlated against the TD data.

APPENDIX A

FORMATS FOR LORAN-C DATA SUPPLIED TO TASC

Formats for Loran-C data supplied to TASC on half-inch magnetic tape by the U.S. Coast Guard are presented in Tables A-1 to A-4. The record lengths are 80 characters for the LC-204 and BRN-5 formats and 40 characters for the Austron-5000 format. All characters which are not included in the tables are "blanks."

TABLE A-1

INTERNAV LC-204 FORMAT FOR DATA SUPPLIED TO TASC

T3484

CHARACTERS	DATA ITEM	DESCRIPTION
1	SWITCH	Control unit switch setting (G for valid, B for invalid)
2-4	DAY	Julian day (Greenwich Mean Time)
5-6	HR	Hours
7-8	MIN	Minutes
9-10	SEC	Seconds
11-14	SNRECDM	Master Signal-to-Noise Ratio (SNR) or Envelope-to-Cycle Difference (ECD) (See char. 38)
15-18	SNRECD1	Secondary 1 SNR or ECD
20-28	TD1	Time difference 1 (0.1 nsec)
33	SITE	Site number
34	---	(1)
35-37	DATAID	Experiment number
38	IDSNRECD	Indicates whether SNR(0) or ECD(1) is printed this record
41-44	SNRECD2	Secondary 2 SNR or ECD
45	ECSM	Master Envelope Command Signal (ECS) indicates whether no cycle jump (0), positive jump (1), or negative jump (2) is commanded by receiver
46	ECS1	Secondary 1 ECS
47	ECS2	Secondary 2 ECS
48	SUFFSIG	Sufficient signal indicator: When converted to a binary number, the 3 digits indicate whether master, secondary 1 and secondary 2 signals are insufficient (0) or sufficient (1)
50-58	TD2	Time difference 2 (0.1 nsec)

TABLE A-2

MAGNAVOX AN/BRN-5 FORMAT (SECONDARY) FOR DATA SUPPLIED TO TASC

T3487

CHARACTERS	DATA ITEM	DESCRIPTION
1	IDENT	Record type indicator: secondary 1 (2) or secondary 2 (3)
2-4	DAY	Julian day (Greenwich Mean Time)
5-6	HR	Hours
7-8	MIN	Minutes
9-10	SEC	Seconds
12	SITE	Site number
13-15	DATAID	Experiment number
17	SUFSIG	Secondary 1 or 2 signal status: When converted to a binary number, first digit indicates whether (1) or not (0) signal is present and second digit whether (1) or not (0) station is blinking
19-27	TD	Time difference 1 or 2 (0.1 nsec)
29-37	TOA	Time of arrival 1 or 2 (0.1 nsec)
39-42	RMSTOA	RMS time of arrival 1 or 2 (nsec)
44-46	ETE	Secondary 1 or 2 envelope time estimate (0.1 μsec). Similar to ECD
48-53	SIGLEV	Secondary 1 or 2 signal level (0.24414 mv)
55-58	FRQNT12	Notch filter frequency (0.1 KHz). For notch 1 if char. 1 = 2; for notch 2 if char. 1 = 3
60-61	RECATTEN	Receiver attenuation (dB) for secondary 1 or 2 signal
63-66	SNR	Secondary 1 or 2 signal-to-noise ratio (0.1 dB)

TABLE A-3
MAGNAVOX AN/BRN-5 FORMAT (MASTER) FOR DATA SUPPLIED TO TASC

T3486

CHARACTERS	DATA ITEM	DESCRIPTION
1	IDENT	Master record type indicator (1)
2-4	DAY	Julian day (Greenwich Mean Time)
5-6	HR	Hours
7-8	MIN	Minutes
9-10	SEC	Seconds
12	SITE	Site number
13-15	DATAID	Experiment number
17	SUFSIG	Master signal status: When converted to a binary number, first digit indicates whether (1) or not (0) signal is present and second digit whether (1) or not (0) station is blinking
19	ENVSKY	When converted to a binary number, first digit indicates whether (0) or not (1) envelope servo is enabled and second digit whether (1) or not (0) skywave detection is enabled
20	SYNINTER	No synchronous interference (0), even synchronous harmonic present (1), or odd synchronous harmonic present (2)
21	TEMPCOMP	Temperature compensation performed (1) or not performed (0) in last 100-sec interval
23-27	DELAY	Relative receiver time delay (nsec)
29-37	TOA	Master time of arrival (0.1 nsec)
39-42	RMSTOA	Master RMS time of arrival (nsec)
44-46	ETE	Master envelope time estimate (0.1 μsec) (Similar to ECD)
48-53	SIGLEV	Master signal level (0.24414 mv)
56-58	COUPATTE	Antenna coupler attenuation (dB)
60-61	RECATTEN	Receiver attenuation (dB) for master signal
63-66	SNR	Master signal-to-noise ratio (0.1 dB)

TABLE A-4

AUSTRON-5000 FORMAT FOR DATA SUPPLIED TO TASC*

CHARACTERS	DATA ITEM	DESCRIPTION
2	STATION	Station designator (M, X, Y, or Z)
4-5	MODE	Receiver operating mode (AC, AV, AF, AW, AS, AT, or K)
8-10	GAIN	Receiver gain number
12-15	SNR	S gnal-to-noise ratio
17-21	CYCLE	Receiver cycle number
23-30	TOA	Time-of-arrival relative to internal oscillator (μsec)
32-39	TD	Time difference (μsec)

*Time is contained in a separate record with the following format: DAY(3-5), HR(7-8), MIN(10-11), and SEC(13-14)

APPENDIX B

FORMATS FOR LORAN-C DATA DELIVERED TO U.S. COAST GUARD

Formats for Loran-C data delivered to the U.S. Coast Guard on half-inch magnetic tape are presented in Tables B-1 to B-5. The record lengths are 130 characters for all receiver formats and 40 characters for the LPA format. All characters which are not included in the tables are "blanks."

TABLE B-1

INTERNAV LC-204 FORMAT FOR DATA DELIVERED TO U.S. COAST GUARD

T3488

CHARACTERS	DATA ITEM	DESCRIPTION
1-5	OBS	Record Number
7	SITE	*
9-13	RECTYPE	Receiver type (LC204)
15	RECNUM	Receiver number
17-19	DAY	*
21-22	HR	*
24-25	MIN	*
27-28	SEC	*
30-39	TD1	Time difference 1 (μsec)
41-46	DIFCORR1	Differential correction for TD1 (μsec)
48-57	TD2	Time difference 2 (μsec)
59-64	DIFCORR2	Differential correction for TD2 (μsec)
66	IDSNRECD	*
68-71	SNRECDM	*
73-76	SNRECD1	*
78-81	SNRECD2	*
83	SWITCH	*
85-87	DATAID	*
89	ECSM	*
91	ECS1	*
93	ECS2	*
95	SUFFSIG	*
97-102	TD1MARKS	Editing Marks for TD1
104-109	TD2MARKS	Editing Marks for TD2
111-118	TIME	Time in sec since beginning of 1979

*These data items are described in Table A-1

TABLE B-2

MAGNAVOX AN/BRN-5 FORMAT (SECONDARY) FOR DATA DELIVERED TO U.S. COAST GUARD

T-3491

CHARACTERS	DATA ITEM	DESCRIPTION
1-5	OBS	Record number
7	SITE	*
9-13	RECTYPE	Receiver type (BRN5)
15	RECNUM	Receiver number
17-19	DAY	*
21-22	HR	*
24-25	MIN	*
27-28	SEC	*
30-39	TD	Time difference 1 or 2 (μsec)
41-46	DIFCORR1	Differential correction for TD (μsec)
48-57	TOA	Time of arrival 1 or 2 (μsec)
59-64	DIFCORR2	Differential correction for TOA (μsec)
66-69	RMSTOA	*
71-74	SNR	*
76-78	ETE	*
80-82	DATAID	*
84	SUFSIG	*
86-91	SIGLEV	*
93-94	RECATTEN	*
96-99	FRQNT12	*
101	IDENT	*
103-108	TDMARKS	Editing marks for TD
110-115	TOAMARKS	Editing marks for TOA
117-124	TIME	Time in sec since beginning of 1979

*These data items are described in Table A-2

TABLE B-3

MAGNAVOX AN/BRN-5 FORMAT (MASTER) FOR DATA DELIVERED TO U.S. COAST GUARD

T3490

CHARACTERS	DATA ITEM	DESCRIPTION
1-5	OBS	Record Number
7	SITE	*
9-13	RECTYPE	Receiver Type (BRN5)
15	RECNUM	Receiver number
17-19	DAY	*
21-22	HR	*
24-25	MIN	*
27-28	SEC	*
30-39	TOA	Master time of arrival (μsec)
41-44	RMSTOA	*
46-49	SNR	*
51-53	ETE	*
55-57	DATAID	*
59	SUFSIG	*
61	ENVSKY	*
63	SYNINTER	*
65	TEMPCOMP	*
67-71	DELAY	*
73-78	SIGLEV	*
80-82	COUPATTE	*
84-85	RECATTEN	*
87	IDENT	*
89-94	TOAMARKS	Editing marks for TOA
96-103	TIME	Time in sec since beginning of 1979

*These data items are described in Table A-3

TABLE B-4

AUSTRON-5000 FORMAT FOR DATA DELIVERED TO U.S. COAST GUARD

CHARACTERS	DATA ITEM	DESCRIPTION
1-6	OBS	Record number
8	SITE	Site number
10-13	RECTYPE	Receiver type (AUST)
15	RECNUM	Receiver number
17-19	DAY	*
21-22	HR	*
24-25	MIN	*
27-28	SEC	*
30-37	TD	*
39-44	DIFCORR	Differential correction for TD (μsec)
46-47	MODE	*
49-51	GAIN	*
53-56	SNR	*
58-62	CYCLE	*
64-71	TOA	*
73-78	TDMARKS	Editing marks for TD
80-87	TIME	Time in sec since beginning of 1979

*These data items are described in Table A-4.

TABLE B-5

FORMAT FOR LPA DATA DELIVERED
TO U.S. COAST GUARD

CHARACTERS	DATA ITEM	DESCRIPTION
1-5	OBS	Record number
7-9	DAY	Julian day (Greenwich Mean Time)
11-12	HR	Hours
14-15	MIN	Minutes
17-18	SEC	Seconds
20-23	LPA	Local phase adjustment (nsec)
25	STATION	Loran-C transmitter (X, Y, Z), or "B" or "E" to indicate beginning or end of segment of LPAs for which time is uncertain*
27	MASTER	Set to "*" if LPA is applied through master and other two secondaries
29-36	TIME	Time in sec since beginning of 1979

*The LPA times are known to lie between the B-time and E-time. LPA times for the records between the B- and E-records are set to the B-time.

APPENDIX C
PARTIAL LISTING OF LORAN-C DATA BASE

Examples of the data formats described in Appendix B are presented in Figs. C-1 to C-5. Lead and final file records are not included in these listings, but are included on the magnetic tapes. Column labels are provided here for convenience, but are not included on the magnetic tapes.

OBS	SITE	RECTYPE	RECNUM	DAY	HR	MIN	SEC	TDI	DIFCORR1	TD2	DIFCORR2	IDSNRECD	SNRECDM	SNRECDI	SNRECD2	SWITCH	DATAID	ECSM	ECS1	ECS2	SUFFSIG	TOIMARKS	TO2MARKS	TIME
0	1	LC204	1	183	18	15	0	22210.2298	-0.014	33416.6599	0.031	0	140	105	353	G	712	0	0	0	7	Y000C0	Z000C0	15790500
1	1	LC204	1	183	18	30	0	22210.2451	-0.026	33416.6701	0.001	1	709	785	826	G	712	0	0	0	7	Y000C0	Z000C0	15791400
2	1	LC204	1	183	18	45	0	22210.2393	-0.027	33416.6629	0.000	0	141	110	340	G	712	0	0	0	7	Y000C0	Z000C0	15792300
3	1	LC204	1	183	19	0	0	22210.2379	-0.027	33416.6654	0.000	1	831	797	813	G	712	0	0	0	7	Y000C0	Z000C0	15793200
4	1	LC204	1	183	19	15	0	22210.2389	-0.028	33416.6606	-0.000	0	146	116	364	G	712	0	0	0	7	Y000C0	Z000C0	15794100
5	1	LC204	1	183	19	30	0	22210.2430	-0.028	33416.6644	-0.000	1	754	785	714	G	712	0	0	0	7	Y000C0	Z000C0	15795000
6	1	LC204	1	183	19	45	0	22210.2447	-0.028	33416.6722	-0.001	0	165	106	388	G	712	0	0	0	7	Y000C0	Z000C0	15795900
7	1	LC204	1	183	20	0	0	22210.2458	-0.029	33416.6714	-0.001	1	789	783	677	G	712	0	0	0	7	Y000C0	Z000C0	15796800
8	1	LC204	1	183	20	15	0	22210.2453	-0.029	33416.6751	-0.001	0	186	110	390	G	712	0	0	0	7	Y000C0	Z000C0	15797700
9	1	LC204	1	183	20	30	0	22210.2478	-0.029	33416.6747	-0.001	1	828	789	847	G	712	0	0	0	7	Y000C0	Z000C0	15798600
10	1	LC204	1	183	20	45	0	22210.2509	-0.030	33416.6753	-0.002	0	151	120	433	G	712	0	0	0	7	Y000C0	Z000C0	15799500
11	1	LC204	1	183	21	0	0	22210.2471	-0.030	33416.6767	-0.002	1	798	751	763	G	712	0	0	0	7	Y000C0	Z000C0	15800400
12	1	LC204	1	183	21	15	0	22210.2426	-0.021	33416.6847	-0.002	0	173	113	397	G	712	0	0	0	7	Y000C0	Z000C0	15801300
13	1	LC204	1	183	21	30	0	22210.2389	-0.031	33416.6774	0.008	1	779	811	796	G	712	0	0	0	7	Y000C0	Z000C0	15802200
14	1	LC204	1	183	21	45	0	22210.2457	-0.031	33416.6843	-0.003	0	188	104	351	G	712	0	0	0	7	Y000C0	Z000C0	15803100
15	1	LC204	1	183	22	0	0	22210.2471	-0.032	33416.6848	0.007	1	783	800	719	G	712	0	0	0	7	Y000C0	Z000C0	15804000
16	1	LC204	1	183	22	15	0	22210.2373	-0.032	33416.6627	-0.003	0	165	102	336	G	712	0	0	0	7	Y000C0	Z000C0	15804900
17	1	LC204	1	183	22	30	0	22210.2467	-0.033	33416.6755	-0.003	1	806	771	839	G	712	0	0	0	7	Y000C0	Z000C0	15805800
18	1	LC204	1	183	22	45	0	22210.2479	-0.033	33416.6756	-0.004	0	159	105	391	G	712	0	0	0	7	Y000C0	Z000C0	15806700
19	1	LC204	1	183	23	0	0	22210.2532	-0.033	33416.6763	-0.004	1	806	781	804	G	712	0	0	0	7	Y000C0	Z000C0	15807600
20	1	LC204	1	183	23	15	0	22210.2357	-0.024	33416.6704	-0.004	0	166	110	394	G	712	0	0	0	7	Y000C0	Z000C0	15808500
21	1	LC204	1	183	23	30	0	22210.2383	-0.034	33416.6757	-0.004	1	797	805	760	G	712	0	0	0	7	Y000C0	Z000C0	15809400
22	1	LC204	1	183	23	45	0	22210.2356	-0.035	33416.6818	-0.005	0	162	115	410	G	712	0	0	0	7	Y000C0	Z000C0	15810300
23	1	LC204	1	184	0	0	0	22210.2349	-0.025	33416.6697	-0.005	1	811	801	761	G	712	0	0	0	7	Y000C0	Z000C0	15811200
24	1	LC204	1	184	0	15	0	22210.2383	-0.035	33416.6666	-0.005	0	176	106	433	G	712	0	0	0	7	Y000C0	Z000C0	15812100
25	1	LC204	1	184	0	30	0	22210.2319	-0.036	33416.6695	-0.005	1	789	790	728	G	712	0	0	0	7	Y000C0	Z000C0	15813000
26	1	LC204	1	184	0	45	0	22210.2415	-0.036	33416.6641	-0.006	0	162	103	426	G	712	0	0	0	7	Y000C0	Z000C0	15813900
27	1	LC204	1	184	1	0	0	22210.2435	-0.036	33416.6699	-0.006	1	821	792	962	G	712	0	0	0	7	Y000C0	Z000C0	15814800
28	1	LC204	1	184	1	15	0	22210.2420	-0.037	33416.6659	-0.006	0	174	117	453	G	712	0	0	0	7	Y000C0	Z000C0	15815700
29	1	LC204	1	184	1	30	0	22210.2508	-0.037	33416.6881	-0.006	1	798	805	728	G	712	0	0	0	7	Y000C0	Z000C0	15816600
30	1	LC204	1	184	1	45	0	22210.2448	-0.028	33416.6692	0.013	0	224	144	667	G	712	0	0	0	7	Y000C0	Z000C0	15817500
31	1	LC204	1	184	2	0	0	22210.2506	-0.038	33416.6703	0.003	1	827	789	766	G	712	0	0	0	7	Y000C0	Z000C0	15818400
32	1	LC204	1	184	2	15	0	22210.2544	-0.038	33416.6495	0.003	0	211	137	836	G	712	0	0	0	7	Y000C0	Z000C0	15819300
33	1	LC204	1	184	2	30	0	22210.2548	-0.039	33416.6741	0.002	1	825	791	771	G	712	0	0	0	7	Y000C0	Z000C0	15820200
34	1	LC204	1	184	2	45	0	22210.2504	-0.029	33416.6636	0.002	0	418	230	932	G	712	0	0	0	7	Y000C0	Z000C0	15821100
35	1	LC204	1	184	3	0	0	22210.2519	-0.040	33416.6621	0.002	1	847	782	867	G	712	0	0	0	7	Y000C0	Z000C0	15822000
36	1	LC204	1	184	3	15	0	22210.2393	-0.030	33416.6432	0.002	0	513	339	1275	G	712	0	0	0	7	Y000C0	Z000C0	15822900
37	1	LC204	1	184	3	30	0	22210.2432	-0.040	33416.6684	0.001	1	843	832	888	G	712	0	0	0	7	Y000C0	Z000C0	15823800
38	1	LC204	1	184	3	45	0	22210.2393	-0.041	33416.6572	0.001	0	703	425	1544	G	712	0	0	0	7	Y000C0	Z000C0	15824700
39	1	LC204	1	184	4	0	0	22210.2442	-0.041	33416.6544	0.001	1	788	795	763	G	712	0	0	0	7	Y000C0	Z000C0	15825600
40	1	LC204	1	184	4	15	0	22210.2421	-0.041	33416.6447	0.001	0	803	418	1644	G	712	0	0	0	7	Y000C0	Z000C0	15826500
41	1	LC204	1	184	4	30	0	22210.2517	-0.042	33416.6471	0.000	1	782	798	782	G	712	0	0	0	7	Y000C0	Z000C0	15827400
42	1	LC204	1	184	4	45	0	22210.2449	-0.042	33416.6286	-0.010	0	759	401	1879	G	712	0	0	0	7	Y000C0	Z000C0	15828300
43	1	LC204	1	184	5	0	0	22210.2384	-0.043	33416.6825	-0.030	1	739	804	923	G	712	0	0	0	7	Y000C0	Z000C0	15829200
44	1	LC204	1	184	5	15	0	22210.2452	-0.043	33416.6544	-0.030	0	902	514	1930	G	712	0	0	0	7	Y000C0	Z000C0	15830100
45	1	LC204	1	184	5	30	0	22210.2490	-0.043	33416.6632	-0.031	1	785	823	744	G	712	0	0	0	7	Y000C0	Z000C0	15831000
46	1	LC204	1	184	5	45	0	22210.2495	-0.044	33416.6576	-0.031	0	970	488	2018	G	712	0	0	0	7	Y000C0	Z000C0	15831900

Figure C-1 Partial Listing of Internav LC-204 Data

OBS	SITE	RECTYPE	RECNUM	DAY	HR	MIN	SEC	ID	DIFCORR1	TOA	DIFCORR2	RNSTOA	SNR	ETE	DATAID	SUFSIG	SIGLEV	RECATTEN	FRONTI2	IDENT	IOMARKS	IOAMARKS	TIME
1	2	BRN5	1	129	20	15	0	21282.2252	0.000	22283.0842	0.000	1	-46	410	1	0	-3428	45	1225	2	Y0203U	Y0****	111321 00
2	2	BRN5	1	129	20	15	0	33290.8647	0.000	34291.7237	0.000	1	-6	407	1	0	-5993	44	1400	3	Z0003S	Z0****	111321 00
3	2	BRN5	1	129	20	30	0	21283.2756	0.000	22284.1373	0.000	2	-24	406	1	0	-4029	45	1400	2	Y0203U	Y0****	111330 00
4	2	BRN5	1	129	20	30	0	33290.8917	0.000	34291.7534	0.000	1	17	408	1	0	-8871	41	1225	3	Z0003S	Z0****	111330 00
5	2	BRN5	1	129	20	45	0	21283.9069	0.000	22284.7575	0.000	1	-3	408	1	0	-6144	42	1395	2	Y0203U	Y0****	111339 00
6	2	BRN5	1	129	20	45	0	33291.1504	0.000	34292.0010	0.000	1	1	409	1	0	-6997	42	1225	3	Z0003S	Z0****	111339 00
7	2	BRN5	1	129	21	0	0	21283.9802	0.000	22284.8521	0.000	1	-24	405	1	0	-4116	34	2260	2	Y0203U	Y0****	111348 00
8	2	BRN5	1	129	21	0	0	33291.0659	0.000	34291.9378	0.000	1	-37	406	1	0	-3817	38	1225	3	Z0003S	Z0****	111348 00
9	2	BRN5	1	129	21	15	0	21284.6739	0.000	22285.5591	0.000	2	-25	409	1	0	-5557	42	1225	2	Y0203U	Y0****	111357 00
10	2	BRN5	1	129	21	15	0	33291.0856	0.000	34291.9708	0.000	1	-30	405	1	0	-4395	46	1400	3	Z0003S	Z0****	111357 00
11	2	BRN5	1	129	21	30	0	21285.5476	0.000	22286.4440	0.000	2	-40	407	1	0	-3397	36	2260	2	Y0203U	Y0****	111366 00
12	2	BRN5	1	129	21	30	0	33290.7517	0.000	34291.6482	0.000	1	-37	408	1	0	-3193	40	1225	3	Z0003S	Z0****	111366 00
13	2	BRN5	1	129	21	45	0	21285.9640	0.000	22286.8365	0.000	2	-31	412	1	0	-4259	34	2265	2	Y0203U	Y0****	111375 00
14	2	BRN5	1	129	21	45	0	33290.9049	0.000	34291.7774	0.000	1	-27	408	1	0	-4199	37	1225	3	Z0003S	Z0****	111375 00
15	2	BRN5	1	129	22	0	0	21286.0979	0.000	22286.9823	0.000	1	-18	409	1	0	-5246	39	1225	2	Y0203U	Y0****	111384 00
16	2	BRN5	1	129	22	0	0	33290.8531	0.000	34291.7375	0.000	1	-29	405	1	0	-3648	48	740	3	Z0003S	Z0****	111384 00
17	2	BRN5	1	129	22	15	0	21287.0931	0.000	22287.9802	0.000	1	-30	408	1	0	-5185	43	1225	2	Y0203U	Y0****	111393 00
18	2	BRN5	1	129	22	15	0	33290.8478	0.000	34291.7349	0.000	1	-12	408	1	0	-5113	45	745	3	Z0003S	Z0****	111393 00
19	2	BRN5	1	129	22	30	0	21288.3689	0.000	22289.2589	0.000	1	-56	413	1	0	-3200	38	1225	2	Y0203U	Y0****	111402 00
20	2	BRN5	1	129	22	30	0	33290.8655	0.000	34291.7554	0.000	1	-13	405	1	0	-4696	35	2260	3	Z0003S	Z0****	111402 00
21	2	BRN5	1	129	22	45	0	21289.4821	0.000	22290.3663	0.000	1	-38	410	1	0	-4863	34	730	2	Y0203U	Y0****	111411 00
22	2	BRN5	1	129	22	45	0	33290.8687	0.000	34291.7829	0.000	1	-17	404	1	0	-4863	36	1230	3	Z0003S	Z0****	111411 00
23	2	BRN5	1	129	23	0	0	21289.6496	0.000	22290.5348	0.000	1	-38	410	1	0	-4487	34	1225	2	Y0203U	Y0****	111420 00
24	2	BRN5	1	129	23	0	0	33290.8465	0.000	34291.7316	0.000	1	-1	407	1	0	-5986	35	1890	3	Z0003S	Z0****	111420 00
25	2	BRN5	1	129	23	15	0	21290.7840	0.000	22291.6803	0.000	2	-30	414	1	0	-3905	35	1225	2	Y0203U	Y0****	111429 00
26	2	BRN5	1	129	23	15	0	33290.8575	0.000	34291.7538	0.000	1	-9	407	1	0	-5049	35	2155	3	Z0003S	Z0****	111429 00
27	2	BRN5	1	129	23	30	0	21291.2473	0.000	22292.1377	0.000	2	-25	410	1	0	-3220	37	1230	2	Y0203U	Y0****	111438 00
28	2	BRN5	1	129	23	30	0	33290.8459	0.000	34291.7364	0.000	1	-8	408	1	0	-6585	36	740	3	Z0003S	Z0****	111438 00
29	2	BRN5	1	129	23	45	0	21291.2534	0.000	22292.1584	0.000	2	-33	409	1	0	-3251	37	1225	2	Y0203U	Y0****	111447 00
30	2	BRN5	1	129	23	45	0	33290.8700	0.000	34291.7750	0.000	1	-22	408	1	0	-3626	38	740	3	Z0003S	Z0****	111447 00
31	2	BRN5	1	130	0	0	0	21292.3579	0.000	22293.2383	0.000	1	-33	409	1	0	-5162	33	1225	2	Y0203U	Y0****	111456 00
32	2	BRN5	1	130	0	0	0	33290.8612	0.000	34291.7416	0.000	1	-9	407	1	0	-5184	35	1820	3	Z0003U	Z0****	111456 00
33	2	BRN5	1	130	0	15	0	21292.8056	0.000	22293.7751	0.000	2	-49	411	1	0	-4084	35	2265	2	Y0203U	Y0****	111465 00
34	2	BRN5	1	130	0	15	0	33290.8610	0.000	34291.7507	0.000	1	-15	406	1	0	-4484	36	740	3	Z0003U	Z0****	111465 00
35	2	BRN5	1	130	0	30	0	21287.6416	0.000	22288.5466	0.000	20	-391	403	1	2	-81	38	1225	2	Y2203U	Y2****	111474 00
36	2	BRN5	1	130	0	30	0	33290.8643	0.000	34291.7693	0.000	1	-13	411	1	0	-4176	46	740	3	Z0003U	Z0****	111474 00
37	2	BRN5	1	130	0	45	0	22363.0875	0.000	23363.1451	0.000	1	-30	412	1	0	-5887	42	740	2	Y0003G	Y0****	111483 00
38	2	BRN5	1	130	0	45	0	33290.8446	0.000	34290.9021	0.000	2	-23	405	1	0	-5072	45	1225	3	Z0003U	Z0****	111483 00
39	2	BRN5	1	130	1	0	0	22363.9425	0.000	23363.9687	0.000	2	-60	411	1	0	-3369	38	1670	2	Y0103U	Y0****	111492 00
40	2	BRN5	1	130	1	0	0	33290.8829	0.000	34290.9091	0.000	1	-40	407	1	0	-4250	38	1225	3	Z0003U	Z0****	111492 00
41	2	BRN5	1	130	1	15	0	22363.8273	0.000	23363.8632	0.000	2	-75	413	1	0	-2716	38	1230	2	Y0103U	Y0****	111501 00
42	2	BRN5	1	130	1	15	0	33290.8594	0.000	34290.8953	0.000	1	-57	406	1	0	-3027	40	735	3	Z0003U	Z0****	111501 00
43	2	BRN5	1	130	1	30	0	22363.4200	0.000	23363.4569	0.000	3	-85	410	1	0	-2624	38	1225	2	Y0003G	Y0****	111510 00
44	2	BRN5	1	130	1	30	0	33290.8327	0.000	34290.8697	0.000	2	-67	410	1	0	-3175	40	740	3	Z0003U	Z0****	111510 00
45	2	BRN5	1	130	1	45	0	22363.4015	0.000	23363.4271	0.000	3	-89	407	1	0	-2416	40	1225	2	Y0003G	Y0****	111519 00
46	2	BRN5	1	130	1	45	0	33290.8744	0.000	34290.8998	0.000	2	-76	413	1	0	-3093	40	1945	3	Z0003U	Z0****	111519 00
47	2	BRN5	1	130	2	0	0	22363.3306	0.000	23363.3807	0.000	3	-87	404	1	0	-2426	39	740	2	Y0003I	Y0****	111528 00

Figure C-2 Partial Listing of Magnavox AN/BRN-5 Secondary Data

OBS	SITE	RECTYPE	RECNUM	DAY	HR	MIN	SEC	TOA	RNSTOA	SNR	ETE	DATAID	SUPSIG	ENVSKY	SYNINTER	TEMPCOMP	DELAY	SIGLEV	COUPATTEN	RECATTEN	IDENT	TOAMARKS	TIME
1	2	BRNS	1	129	20	15	0	1000.8589	1	11	410	1	0	1	0	1	0	-6624	50	46	1	NO****	11132100
2	2	BRNS	1	129	20	30	0	1000.8617	1	17	409	1	0	1	0	1	0	-6629	50	45	1	NO****	11133000
3	2	BRNS	1	129	20	45	0	1000.8506	1	19	407	1	0	1	0	1	0	-8187	50	44	1	NO****	11133900
4	2	BRNS	1	129	21	0	0	1000.8719	1	7	410	1	0	1	0	1	0	-5735	60	38	1	NO****	11134800
5	2	BRNS	1	129	21	15	0	1000.8852	1	0	411	1	0	1	0	1	0	-6242	50	46	1	NO****	11135700
6	2	BRNS	1	129	21	30	0	1000.8965	1	9	410	1	0	1	0	1	0	-7036	60	36	1	NO****	11136600
7	2	BRNS	1	129	21	45	0	1000.8725	1	6	411	1	0	1	0	1	0	-6841	60	35	1	NO****	11137500
8	2	BRNS	1	129	22	0	0	1000.8844	1	6	410	1	0	1	0	1	0	-5861	50	47	1	NO****	11138400
9	2	BRNS	1	129	22	15	0	1000.8871	1	3	410	1	0	1	0	1	0	-6281	50	47	1	NO****	11139300
10	2	BRNS	1	129	22	30	0	1000.8899	1	13	410	1	0	1	0	1	0	-7996	60	34	1	NO****	11140200
11	2	BRNS	1	129	22	45	0	1000.8842	1	-4	410	1	0	1	0	1	0	-5112	60	39	1	NO****	11141100
12	2	BRNS	1	129	23	0	0	1000.8852	1	8	410	1	0	1	0	1	0	-6520	60	37	1	NO****	11142000
13	2	BRNS	1	129	23	15	0	1000.8963	1	-3	411	1	0	1	0	1	0	-4973	60	38	1	NO****	11142900
14	2	BRNS	1	129	23	30	0	1000.8904	1	-4	411	1	0	1	0	1	0	-4737	60	39	1	NO****	11143800
15	2	BRNS	1	129	23	45	0	1000.9050	1	-5	412	1	0	1	0	1	0	-5452	60	38	1	NO****	11144700
16	2	BRNS	1	130	0	0	0	1000.8804	1	21	410	1	0	1	0	1	0	-10257	60	41	1	NO****	11145600
17	2	BRNS	1	130	0	15	0	1000.8897	1	-2	411	1	0	1	0	1	0	-5981	60	37	1	NO****	11146500
18	2	BRNS	1	130	0	30	0	1000.9050	1	-9	412	1	0	1	0	1	0	-5374	50	48	1	NO****	11147400
19	2	BRNS	1	130	0	45	0	1000.0576	0	-12	408	1	0	1	0	1	0	-5287	50	48	1	NO****	11148300
20	2	BRNS	1	130	1	0	0	1000.0262	1	-13	413	1	0	1	0	1	0	-5451	60	38	1	NO****	11149200
21	2	BRNS	1	130	1	15	0	1000.0359	1	-31	412	1	0	1	0	1	0	-4613	60	39	1	NO****	11150100
22	2	BRNS	1	130	1	30	0	1000.0370	1	-31	411	1	0	1	0	1	0	-5158	60	37	1	NO****	11151000
23	2	BRNS	1	130	1	45	0	1000.0255	2	-44	412	1	0	1	0	1	0	-4397	60	39	1	NO****	11151900
24	2	BRNS	1	130	2	0	0	1000.0500	2	-41	410	1	0	1	0	1	0	-3633	60	42	1	NO****	11152800
25	2	BRNS	1	130	2	15	0	1000.0303	2	-50	410	1	0	1	0	1	0	-3639	60	41	1	NO****	11153700
26	2	BRNS	1	130	2	30	0	1000.0437	2	-42	410	1	0	1	0	1	0	-4933	60	38	1	NO****	11154600
27	2	BRNS	1	130	2	45	0	1000.0189	2	-40	411	1	0	1	0	1	0	-4272	60	40	1	NO****	11155500
28	2	BRNS	1	130	3	0	0	1000.0573	2	-44	409	1	0	1	0	1	0	-3561	60	41	1	NO****	11156400
29	2	BRNS	1	130	3	15	0	1000.0178	2	-47	409	1	0	1	0	1	0	-3342	60	41	1	NO****	11157300
30	2	BRNS	1	130	3	30	0	1000.0324	2	-52	410	1	0	1	0	1	0	-3329	60	42	1	NO****	11158200
31	2	BRNS	1	130	3	45	0	1000.0602	2	-55	410	1	0	1	0	1	0	-3495	60	41	1	NO****	11159100
32	2	BRNS	1	130	4	0	0	1000.0550	2	-46	409	1	0	1	0	1	0	-4165	60	39	1	NO****	11160000
33	2	BRNS	1	130	4	15	0	1000.0188	2	-52	410	1	0	1	0	1	0	-4038	60	40	1	NO****	11160900
34	2	BRNS	1	130	4	30	0	1000.0149	2	-54	411	1	0	1	0	1	0	-3443	60	42	1	NO****	11161800
35	2	BRNS	1	130	4	45	0	1000.0202	2	-51	408	1	0	1	0	1	0	-3860	60	41	1	NO****	11162700
36	2	BRNS	1	130	5	0	0	1000.0446	1	-52	409	1	0	1	0	1	0	-4510	60	40	1	NO****	11163600
37	2	BRNS	1	130	5	15	0	1000.0263	2	-54	410	1	0	1	0	1	0	-4128	60	40	1	NO****	11164500
38	2	BRNS	1	130	5	30	0	1000.0244	1	-66	407	1	0	1	0	1	0	-3569	60	42	1	NO****	11165400
39	2	BRNS	1	130	5	45	0	1000.0149	2	-69	410	1	0	1	0	1	0	-3161	60	42	1	NO****	11166300
40	2	BRNS	1	130	6	0	0	1000.0602	2	-68	408	1	0	1	0	1	0	-3394	60	41	1	NO****	11167200
41	2	BRNS	1	130	6	15	0	1000.0392	2	-71	408	1	0	1	0	1	0	-2856	60	43	1	NO****	11168100
42	2	BRNS	1	130	6	30	0	1000.0453	2	-66	409	1	0	1	0	1	0	-3631	60	42	1	NO****	11169000
43	2	BRNS	1	130	6	45	0	1000.0454	2	-68	412	1	0	1	0	1	0	-3604	60	41	1	NO****	11169900
44	2	BRNS	1	130	7	0	0	1000.0221	2	-78	411	1	0	1	0	1	0	-2867	60	43	1	NO****	11170800
45	2	BRNS	1	130	7	15	0	1000.0385	2	-74	410	1	0	1	0	1	0	-2695	60	44	1	NO****	11171700
46	2	BRNS	1	130	7	30	0	1000.0136	2	-56	407	1	0	1	0	1	0	-3425	60	42	1	NO****	11172600
47	2	BRNS	1	130	7	45	0	1000.0378	2	-63	410	1	0	1	0	1	0	-3170	60	42	1	NO****	11173500

Figure C-3 Partial Listing of Magnavox AN/BRN-5 Master Data

OBS	SITE	RECVTYPE	RECNUM	DAY	HR	MIN	SEC	TD	DIFCORR	MODE	GAIN	SNR	CYCLE	TOA	REMARKS	TIME
1	8	AUST	1	142	3	0	5	0.00	0.000	AT	64	49	2.79	52129.22	M******	12193205
2	8	AUST	1	142	3	0	5	11259.70	0.005	AT	61	35	2.80	4088.92	X000000	12193205
3	8	AUST	1	142	3	0	5	22363.89	-0.020	AT	68	80	2.78	15193.10	Y000000	12193205
4	8	AUST	1	142	3	0	5	33200.41	-0.005	AT	60	25	2.76	26029.63	Z000000	12193205
5	8	AUST	1	142	3	15	5	0.00	0.000	AT	64	53	2.78	52135.15	M******	12194105
6	8	AUST	1	142	3	15	5	11259.71	-0.005	AT	61	32	2.78	4094.85	X000000	12194105
7	8	AUST	1	142	3	15	5	22363.88	-0.010	AT	68	120	2.78	15199.03	Y000000	12194105
8	8	AUST	1	142	3	15	5	33200.41	-0.005	AT	61	17	2.75	26035.56	Z000000	12194105
9	8	AUST	1	142	3	30	5	0.00	0.000	AT	64	48	2.77	52141.14	M******	12195005
10	8	AUST	1	142	3	30	5	11259.69	0.015	AT	61	32	2.78	4100.83	X000000	12195005
11	8	AUST	1	142	3	30	5	22363.87	0.000	AT	68	105	2.78	15205.01	Y000000	12195005
12	8	AUST	1	142	3	30	5	33200.40	0.005	AT	61	20	2.74	26041.54	Z000000	12195005
13	8	AUST	1	142	3	45	5	0.00	0.000	AT	64	48	2.76	52147.28	M******	12195905
14	8	AUST	1	142	3	45	5	11259.71	-0.005	AT	61	29	2.78	4106.96	X000000	12195905
15	8	AUST	1	142	3	45	5	22363.89	-0.020	AT	68	122	2.78	15211.14	Y000000	12195905
16	8	AUST	1	142	3	45	5	33200.42	-0.015	AT	60	14	2.75	26047.67	Z000000	12195905
17	8	AUST	1	142	4	0	5	0.00	0.000	AT	64	38	2.78	52153.39	M******	12196805
18	8	AUST	1	142	4	0	5	11259.68	0.025	AT	61	48	2.78	4113.08	X000000	12196805
19	8	AUST	1	142	4	0	5	22363.86	0.010	AT	68	90	2.78	15217.25	Y000000	12196805
20	8	AUST	1	142	4	0	5	33200.40	0.005	AT	60	19	2.76	26053.79	Z000000	12196805
21	8	AUST	1	142	4	15	5	0.00	0.000	AT	64	45	2.78	52159.51	M******	12197705
22	8	AUST	1	142	4	15	5	11259.71	-0.005	AT	61	23	2.79	4119.21	X000000	12197705
23	8	AUST	1	142	4	15	5	22363.88	-0.010	AT	68	92	2.79	15223.39	Y000000	12197705
24	8	AUST	1	142	4	15	5	33200.41	-0.005	AT	60	16	2.75	26059.92	Z000000	12197705
25	8	AUST	1	142	4	19	58	0.00	0.000	AT	64	37	2.78	52161.51	M******	12197998
26	8	AUST	1	142	4	19	58	11259.70	0.005	AT	61	36	2.79	4121.21	X000000	12197998
27	8	AUST	1	142	4	19	58	22363.87	0.000	AT	68	79	2.79	15225.39	Y000000	12197998
28	8	AUST	1	142	4	19	58	33200.59	0.000	AT	66	81	2.59	26062.10	Z000025	12197998
29	8	AUST	1	142	4	25	31	0.00	0.000	AT	63	38	2.77	52163.79	M******	12198331
30	8	AUST	1	142	4	25	31	11259.69	0.015	AT	61	31	2.79	4123.47	X000000	12198331
31	8	AUST	1	142	4	25	31	22363.86	0.010	AT	68	110	2.79	15227.64	Y000000	12198331
32	8	AUST	1	142	4	25	31	33200.67	0.000	AT	60	20	2.36	26064.46	Z000026	12198331
33	8	AUST	1	142	4	28	53	0.00	0.000	AT	64	49	2.77	52165.17	M******	12198533
34	8	AUST	1	142	4	28	53	11259.69	0.015	AT	61	31	2.79	4124.86	X000000	12198533
35	8	AUST	1	142	4	28	53	22363.85	0.020	AT	68	125	2.78	15229.03	Y000000	12198533
36	8	AUST	1	142	4	28	53	33200.36	0.065	AT	60	23	2.59	26065.51	Z000000	12198533
37	8	AUST	1	142	4	30	5	0.00	0.000	AT	64	34	2.76	52165.66	M******	12198605
38	8	AUST	1	142	4	30	5	11259.70	0.005	AT	60	41	2.79	4125.35	X000000	12198605
39	8	AUST	1	142	4	30	5	22363.86	0.010	AT	67	115	2.78	15229.52	Y000000	12198605
40	8	AUST	1	142	4	30	5	33200.32	0.000	AT	60	16	2.61	26065.98	Z000021	12198605
41	8	AUST	1	142	4	33	6	0.00	0.000	AT	64	45	2.78	52166.93	M******	12198786
42	8	AUST	1	142	4	33	6	11259.68	0.025	AT	61	27	2.78	4126.61	X000000	12198786
43	8	AUST	1	142	4	33	6	22363.85	0.020	AT	68	91	2.78	15230.78	Y000000	12198786
44	8	AUST	1	142	4	33	6	33200.39	0.015	AT	60	16	2.67	26067.32	Z000000	12198786
45	8	AUST	1	142	4	37	52	0.00	0.000	AT	64	51	2.78	52168.89	M******	12199072
46	8	AUST	1	142	4	37	52	11259.71	-0.005	AT	60	41	2.78	4128.60	X000000	12199072
47	8	AUST	1	142	4	37	52	22363.87	0.000	AT	68	152	2.78	15232.76	Y000000	12199072
48	8	AUST	1	142	4	37	52	33200.34	0.000	AT	60	14	2.79	26069.23	Z000021	12199072

Figure C-4 Partial Listing of Austron-5000 Data

OBS	DAY	HR	MIN	SEC	LFA	STATICN	MASTER	TIME
1	130	0	7	1	10	X		11146021
2	130	0	28	38	10	X		11147318
3	130	1	20	50	10	X		11150450
4	130	11	47	25	-20	Z		11188045
5	130	11	47	38	-10	X		11188058
6	130	20	25	9	-10	X		11219109
7	130	20	27	7	-10	Z		11219227
8	130	21	25	2	10	X		11222702
9	130	22	55	52	10	X		11228152
10	131	1	22	37	-10	Z		11236957
11	131	3	18	12	-10	Y		11243892
12	131	3	22	34	-10	Y		11244154
13	131	13	6	39	-10	X		11279199
14	131	13	8	14	-10	Y		11279294
15	131	13	9	4	-10	Z		11279344
16	131	13	39	6	-10	X		11281146
17	131	14	9	27	-10	X		11282967
18	131	14	38	23	-10	X		11284703
19	131	15	8	42	-20	X		11286522
20	131	15	37	40	-10	X		11288260
21	131	17	7	55	-10	X		11293675
22	131	17	53	8	-10	Y		11296388
23	131	18	9	41	-10	Y		11297381
24	131	22	25	46	-10	Y		11312746
25	131	23	40	15	-10	Y		11317215
26	132	0	21	45	10	Z		11319705
27	132	0	52	1	20	Z		11321521
28	132	1	21	47	-10	Y		11323307
29	132	1	22	17	20	Z		11323337
30	132	2	45	10	-10	Y		11328310
31	132	12	24	31	10	X		11363071
32	132	12	24	56	-10	Y		11363096
33	132	12	24	56	-10	Z		11363096
34	132	13	19	20	10	X		11366360
35	132	13	19	30	10	Y		11366370
36	132	13	19	47	-10	Z		11366387
37	132	13	51	37	10	Y		11368297
38	132	15	46	58	-10	X		11375218
39	132	15	50	35	-10	Y		11375835
40	132	15	51	3	-10	Z		11375863
41	132	23	19	44	-10	X		11402384
42	132	23	21	52	-10	Y		11402512
43	132	23	22	11	-10	Z		11402531
44	132	23	51	31	-10	Y		11404291
45	133	0	22	50	-10	Z		11406170
46	133	0	53	24	-10	X		11408004
47	133	0	53	48	-10	Y		11408028
48	133	1	23	18	-10	Y		11409758

Figure C-5 Partial Listing of LPA Data

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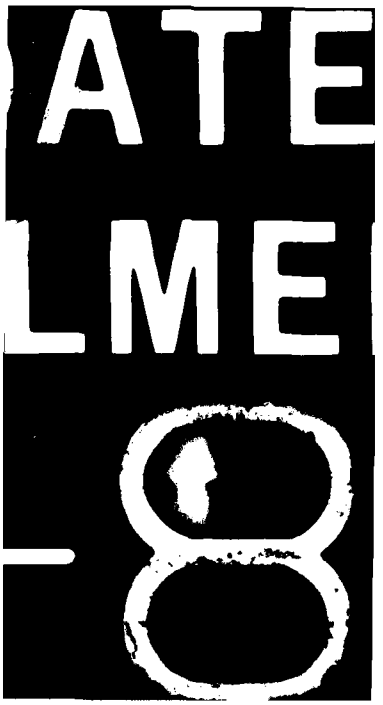
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